A COMPLETE MODELLING GUIDE FOR PRECAST ELEMENT WALL USING TEKLA STRUCTURES

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Bachelor's thesis

Hämeenlinna University Center, Degree Programme in Construction Engineering

Spring semester 2021

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Degree Programme in Construction Engineering
Hämeenlinna University Center Abstract

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Subject A Complete Modelling Guide for Precast Element Wall Using Tekla Structures
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The main objective of this thesis is to serve as a guide for modelling a precast wall and generating the necessary drawings required to produce these elements using Tekla structures. This thesis explains each and every step of the software's operation in depth.

The thesis theoretical section includes the general information about the history and present situation of precast industry. In addition to this, the advantages of using precast elements and modelling the element using Building Information Modelling (BIM) software are explained. The information was collected from various articles and websites.

The practical part of the thesis consists of the use of Tekla Structures for modelling the wall element and explaining all the methodologies used while creating the modelled wall element. Every detail such as a type of concrete, reinforcement, insulation, connection, lifting inserts, wall vemo inserter has been considered while modelling.

This thesis can be used for the educational purposes for the individuals who want to learn modelling in Tekla Structures. It can also be used by the companies as a manual for their interns. This thesis is not intended to be used in the structural design of the wall elements and therefore, no calculation was included.

Keywords Precast, BIM, element design, Tekla Structures
Pages 56 pages including appendices 5 pages.

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1 INTRODUCTION

Concrete has been around for hundreds of years which makes it well-known for its strength and attractive features. In addition to the several known benefits of concrete, the strength of the precast concrete is unique and special on its own way. The precast concrete industry as we know it today originated in the 1900s. John Alexander Brodie an English engineer found out the precast concrete components could be used to quickly construct a structure. Brodie was the first to receive a patent for the precast concrete paneled construction technology. Now the precast concrete industry has grown widely and set a standard in the construction industry.

Precast concrete means engineers enjoy huge freedom in planning and designing the products. Building Information Modelling (BIM) software plays an important role in modelling of precast components. Designers use BIM to generate digital 3D models that include data on physical and functional properties. The data in a model establishes behavior and linkages between model components, as well as specifies the design elements. As a result, if an element in a model is modified, every view in the model is updated to reflect the new modification, which is viewable in section, elevation, and sheet views. The information can be used in sophisticated analysis and simulations, as well as realistic renderings. The design and construction process is lengthy, and there are always chances of mistakes and errors. The architects, engineers, and contractors can unite and work together on a same constructed model which give a greater perception into how their work fits into the final model. (Autodesk, n.d.). The engaged members will have an entry to the entire information database which allows to find the problems and solve them which may come during the design process. Software such as Tekla Structures is the most commonly used software for the modelling of precast element because of its various features. The theoretical part of the thesis deals with the precast construction and the use of BIM in precast construction more in detail.

The main objective of this thesis is to model a structural model of a precast sandwich panel and generate a production drawing of the element. This thesis can also be used as a manual guide for people who want to learn modelling the wall element in Tekla Structures. The thesis describes the various stages of the modelling and generating a production drawing. The work was limited to modelling a single sandwich wall element only. The scope and the workload of the project would have increased if the thesis dealt with the load calculation. There was not any real project while modelling the element. However, a floor layout was used from a free website just to show how to use it as a reference while modelling. The source materials used in this thesis are mainly from the different websites and publications of Autodesk, Trimble, Peikko, Elementtisuunnittelu, etc.

2 PRECAST CONCRETE CONSTRUCTION IN FINLAND

2.1 History of precast concrete construction

Precast concrete construction began in Finland in the beginning of 1950's. After the war, an efficient and economical way of building was searched for, and the solution was found in precast concrete construction that met the needs during that time. In the 1960s, precast concrete production increased as migration flows from countryside to the major cities in pursuit of the jobs resulted in the demand of new housing in the cities. The rapid growth of precast concrete construction also caused problems when there was little training and there were no standards or common norms for the structural solutions, design, and production of precast concrete elements. The major development took place in the 1970's and 80's when open precast building systems were properly developed.

As a result, Betoniteollisuus ry developed the BES system for residential construction in 1968-1970. The fundamental dimension in modular design is nx3M (M=100mm). Load-bearing walls and long span slabs (hollow-core slabs) were selected the construction work. For facades, sandwich panels with mineral wool as an insulation were picked. Later, the development has continued in several projects. Frame-BES for non- residential buildings was developed in 1980-83. In 1980s, standardization continued, with the creation of the Frame-BES material, which defined the recommended dimensions and type of the structural members, the connection details, and the measurement for the column-beam frame. Then the column and beam profiles were standardized. In late 1980's slimmer low- profile and composite beams and hybrid skeleton solutions were developed. For industrial and commercial buildings, long-span prestressed straight or sloped TT-slabs and higher hollow-core slabs up to 500 mm were developed. In parking buildings 1.2 m wide prestressed solid planks are often used with cast in-situ concrete. The most recent system development has focused on thermal and sound insulation properties, connections, floors for bathroom areas and the 3D-design process. (Elementtisuunnittelu/valmisisarakentaminen, n.d.)

2.2 Precast concrete construction

Precast elements are created off-site or in a factory using a mold. With wire mesh or rebar, concrete is poured into a wooden or steel mold. If necessary, prestressed cable may be used in the mold. Then it is cured in a controlled condition, such as factory. The precast concrete is then brought to the construction site and installed.

All precast concrete is not prestressed with cable reinforcement. Thus, it is important to notice weather the concrete is prestressed or not. The strength of the concrete can be increased by adding the reinforcement and can be useful in many buildings and load bearing structures which require maximum strength in concrete. The inclusion of the reinforcement provides tension within the concrete, which is achieve once hardening is complete. (Nitterhouse concrete, n.d.)

The process of using precast concrete is quicker, safer, and the cheaper than the standard concrete regardless the concrete is prestressed or not. The project potential will increase while ensuring the project to complete in the given schedule when using the precast concrete products. When using precast concrete products, the user has the ability to choose any combination of textures, form, or color and integrate facades combining with a strong structure. Thus, the precast concrete products are the most versatile products in construction. (Nitterhouse concrete, n.d.) The precast element is also compatible with old structures and may be made in a variety of sizes, from small pieces to huge open spans. It can also be recycled or reused upon removal or replacement.

Precast concrete elements are used in a variety of project types. One of the reasons precast concrete constructions are so diversified is its adaptability, which includes anything from parking garages, bridges, and office buildings to stadiums, retail stores, and houses. It is apparent that the advantages of precast concrete products may be enjoyed by a wide range of building types. Parking structures, foundations, bridges, culverts, curb inlets and catch basins, sound barriers, and retaining walls are some of the most popular construction projects that employ precast concrete.

Precast concrete products are perfect for a variety of building applications due to its fire-resistant and sound-proof features. Two more compelling reasons to adopt a precast concrete structure are the reduction of dampness and the creation of an energy-efficient atmosphere. (Upceilings post, n.d.) The adaptability of precast concrete may be seen in a wide range of structures, including office buildings, multi-unit housing, hospitals and medical facilities, schools, and retail shopping complexes, among others.

2.3 Benefits of precast concrete

Engineers have more planning and design freedom with precast concrete for commercial and residential constructions. Precast concrete products are delivered to the construction site fully prepared and ready to assemble. It is possible to speed up a project's timetable by employing precast concrete goods, as well as save money by employing concrete materials that are prefabricated offsite.

However, the benefits go beyond ease of use and workflow to include adaptability, control, efficiency, and long-term sustainability, all of which combine to create a superior precast concrete product. Some of the major benefits of using the precast concrete products are briefly explained below.

2.3.1 Versatility

One of the most significant advantages of precast concrete construction is its versatility. Precast concrete may be shaped into a variety of colors, textures, and sizes. As a result, it is widely used in a variety of sectors. The combination of standard structural shapes and the potential of casting custom shapes gives designers maximum flexibility. (Upceilings post, n.d.)

2.3.2 Controlled environment

PCI Certified factories construct precast/prestressed concrete in a regulated environment. Precast concrete is made in a highly controlled environment that eliminates any risk of external activities, such as weather, without compromising the quality of the finished goods or the production schedule. (Nitterhouse concrete, n.d.)

2.3.3 Efficiency

The regulated industrial environment results in efficiency. Precast concrete may be manufactured all year at a facility, which speeds up the overall building process. There is no need to be concerned about arranging concrete pouring on-site when bad weather may cause the entire work to be delayed.

Precast concrete materials may create a building's whole structural frame, increasing site productivity and allowing the entire structure to be completed on a scheduled timetable, increasing the project's overall efficiency. As a result, many construction businesses are turning to precast concrete products as a viable option. (Upceilings post, n.d.)

2.3.4 Sustainability

Manufacturing precast concrete is a sustainable process. Many sustainable building innovators employ precast concrete for LEED certification. (Nitterhouse concrete, n.d.) Natural aggregates such as gravel, sand, rock, and water are used to make concrete. Water that is used in the concrete manufacturing process may be recycled. When operating in a manufacturing environment, waste from bracing and formwork, surplus concrete, and packaging that accumulates on-site after cast-in-place may be reduced. When compared to on-site goods, the materials utilized for precast element buildings are less expensive. As a result, less raw material is taken from the environment, and less material is discarded at the end of a building's existence. When working in a manufacturing setting, safety hazards, noise, and air quality may be managed, making it healthier for construction employees. (Nitterhouse concrete, n.d.)

2.4 Disadvantages of precast

Although adopting a precast element provides a number of benefits, it also has a few drawbacks. Producing a precast product requires a separate plant or facility, which raises costs. It also needs the use of correct formwork for various items. The factory should have sufficient storage space for the final goods. In addition, the manufacturing organization should concentrate on product marketing and sales. The following are some of the significant drawbacks of utilizing precast products.

- The precast product might get damaged during transportation if not handled properly.
- Need proper connections between the precast elements. Sometimes, it becomes difficult to create proper connection.
- Need special equipment for lifting and moving of the precast elements.
- Extra expenses in transportation and handling of the products.
- Precast elements are very difficult to repair.

3 ROLE OF BUILDING INFORMATION MODELLING (BIM) IN PRECAST CONSTRUCTION

3.1 Building Information Modelling (BIM)

BIM (Building Information Modeling) is a smart 3D model-based approach that provides architects, engineers, and construction (AEC) professionals with the knowledge and tools they need to plan, design, construct, and manage buildings and infrastructure more effectively. (Autodesk, n.d.)

Designers can create a digital 3D models with BIM that comprise the data related to physical and functional features. The designed model contains a data specifying the design elements and sets up the way of functioning and connections between model components. Thus, when something is changed in a model, every view is updated with the new changes. The information may be utilized in sophisticated analysis and simulations, as well as for realistic renderings. (Autodesk, n.d.)

Building and infrastructure designs are designed and reported using BIM. With BIM, every last detail of a structure is modeled. The model may be used to research and explore design possibilities, as well as to create visualizations that assist stakeholders see the building before it is completed. The model is then utilized to create construction design documents.

Figure 1. BIM cycle (Structural details, n.d.)

The BIM process generates intelligent data that may be used throughout the lifespan of a construction or infrastructure project.

- **Plan**
  By combining reality capture with real-world data to create context models of the current built and natural surroundings, project planners may better plan their projects.

- **Design**
  Conceptual design, analysis, detailing, and documentation are all completed at this phase. BIM data is used to inform scheduling and logistics in the preconstruction phase.

- **Build**
  Fabrication begins utilizing BIM instructions during this phase. To ensure precise time and efficiency, project construction logistics are communicated with trades and contractors.

- **Operate**
  The BIM data is then applied to the finalized product's operations and maintenance. In the future, BIM data might be utilized for cost-effective renovations or efficient demolition.

According to the United Nations, the world's population will reach 9.7 billion people by 2050. The global AEC sector must seek to smarter, more efficient ways of designing and building not simply to keep up with global demand, but also to help develop smarter, more resilient spaces.

BIM not only makes it easier for designers and construction teams to collaborate, but it also helps them to record the data they generate during the process for use in operations and maintenance. This might be one of the reasons behind BIM's acceptance. This might explain why BIM is becoming more popular throughout the world.

3.2 Tekla Structures for modelling of precast element

Tekla Structures is a cutting-edge structural BIM program for the design and construction of steel and concrete structures. Engineers use it because it combines 3D modeling features. It is utilized for structural steel detailing and precast concrete detailing in the construction sector. It helps structural engineers to design steel and concrete structures from concept to completion. It automates the production of shop drawings.

Models for structural steel, concrete, rebar, and miscellaneous metals may all be created with Tekla. It is, in fact, developed expressly for steel and concrete constructions. Engineers have been using this program to develop structures till today. Engineers have used this program to design skyscrapers, bridges, residential homes, industries, plants, offshore plants, and model stadiums up till now.

Using Tekla software to provide all sorts of precast concrete pieces at the correct time and at the appropriate location is a methodical technique to do so. It is feasible to combine design and details with manufacturing and project management using a building information model. Precast producers can work with contractors and subcontractors to win more contracts by exchanging information more effectively with BIM software. Tekla's BIM software integrates with enterprise resource planning (ERP) systems like EliPlan and automation equipment applications. The following are some of the primary benefits of adopting Tekla Structures for precast concrete producers:

- **Estimation and bidding**
  Estimation and bidding are two of the most important stages of working on a precast concrete building project. A functional system based on models may help you control risk, win more bids, and increase profitability. The user may quickly construct conceptual models and obtain exact amounts for estimating using Tekla software. The visualize structural solutions fulfill production and corporate requirements, and then provide the best option to the customer. Bidding risks are reduced when the amount is accurate. (Trimble Solutions, n.d.)

- **Detailing**
  Errors, inconsistencies in detailed documentation, and inefficient information transfer waste time and resources, resulting in costly rework in the detailing department, manufacturing facility, and on-site. When using Tekla Structures to

describe a structure, the user may detect any potential problems at the office with the building information model, rather than on site.

The program can simulate all forms of precast constructions, including connections, concrete embeds, and even the most intricate rebar. Tekla can deal with any type of material, regardless of its size or difficulty. The Tekla model that was built has all of the information needed to generate drawings, reports, and fabrication data. Tekla automatically updates all documents when a project's model changes, while the information remains constant. This eliminates human error and lowers manual labor. Accurate 3D information promotes cooperation between design, manufacturer, and site by allowing everyone to comprehend the design goal. (Trimble Solutions, n.d.)

- **Fabrication**

  For planning and regulating manufacturing, the precise Tekla models provide a simple way to access numbers, shape, and material information. The software incorporates with the precast concrete and rebar manufacturing gear, and it delivers openly accessible data for production management. When the Tekla model is utilized as a data source, it will always contain the same consistent data to use for material reports, fabrication drawings, and data files prepared for CAM software.

  The in-built models include sequence and status information, which makes planning and tracking production easier and ensures on delivery time. Everyone can use mobile solutions that are simple to use. Everyone may enjoy and look at the visual model information using easy-to-use mobile solutions. This helps fabrication staff to rapidly grasp the design goal, improving both production efficiency and quality. (Trimble Solutions, n.d.)

- **Planning and coordination**

  Tekla's model-based workflows help with project planning, tracking, and keeping all partners in the supply chain informed at all phases of the project. The model's status information is separate and may be used to effectively manage the project and guarantee that it is progressing according to plan.

  The information-rich models make it simpler to comprehend the projects and identify potential difficulties, and everyone is kept informed, which increases safety. It is simpler to adjust to new developments in the project when everyone has the same understanding of the current state of the project. With the 3D visuals, reporting to the customer is a breeze. Model information helps everyone, regardless of location or computer abilities, thanks to simple mobile solutions. (Trimble Solutions, n.d.)

- **Create any precast products and projects**
  Tekla Structures is an excellent program for modeling a wide range of precast products. Tekla Structures can design a wide range of precast materials, including slabs, walls, frame components, steps and staircases, bathroom volumetrics, architectural features, and more.

  Tekla Structures allows users to design any form of structural precast project, including commercial, public, and industrial buildings, as well as unusual structures. Parking structures, office buildings, residential towers, warehouses, bridges, stadiums, and sports facilities are only a few examples of many types of projects.

- **Modern model-based data exchange for precast industry**
  IFC4precast is the future approach of transmitting the constructible model to the production system based on the IFC4 data format, overcoming the limitations of existing file formats, and eliminating factory constraints from the detailed phase. The buildingSMART supported IFC4precast project intends to combine the capabilities of each current precast manufacturing format to develop a contemporary collaborative process that meets the demands of the construction lifecycle and beyond.

  "In practice, this means IFC4 will be enriched with precast manufacturing characteristics so that all relevant intelligence of the constructible model is readable for manufacturing systems without flattening BIM," says Thorsten Hertel, Product Manager Precast Fabrication, Structures Division, who represents Trimble in the IFC4precast project group. (Trimble Solutions, n.d.)

4 MODELLING INSTRUCTIONS FOR PREFABRICATED ELEMENTS

4.1 General

In March 2012, Betoniteollisuus ry, Elementtisuunnittelu, and Tekla jointly published an element modelling guide (BEC2012) for the development of 3D design, data transfer, and modelling of precast concrete elements. The aim of the guide is to define certain ground rules concerning information about modelling of precast concrete elements so that all models reach the standard regardless of the modeler or design company, even if different tools are used while modelling. (Betoniteollisuus ry, 2016)

4.2 Handover of models

Using the model for purposes other than sketching is useful to the project as a whole. Designers can turn the model on to the precast fabrication industry, subcontractors, and other project participants. In line with the project's timeline, the model is handed either in IFC format or the software's native format, depending on the requirement. The goal of handing over the model, according to the instructions, is to benefit from the fact that the production factories receive quantity data straight from the model. (Betoniteollisuus ry, 2016)

4.3 Design requirements

The designers must follow the guidelines, as well as the BEC2012's accuracy levels, data transmission methods, and cooperation requirements. The Design Requirements section explains what should be addressed and agreed upon during the kickoff meeting, as well as the accuracy of element sizes and planning phase execution. (Betoniteollisuus ry, 2016)

4.4 General information about modelling concrete elements

Concrete elements must be modelled in such a way that reports including the data needed by the precast manufacturing industry can be created. For each kind of element, element modeling must be consistent and identical. Tables and reports for each kind of element may have their own definitions. From the standpoint of using the model and enabling automatic data transmission, the elements in the model, as well as the relevant information and equipment, must be recognizable (Betoniteollisuus ry, 2016) Some of the information of the element that should be defined while modeling is given below:

- Element ID / Drawing
- Element type identifier
- Element serial number
- Production serial number
- Number of elements
- ID (GUID)
- Serial number (ACN)
- Installation section
- Floor
- Product type
- Tolerance class (Inner shell)
- Tolerance class (Outer shell)
- Planned lifetime
- Fire class

4.5 Quantity information and tabulation

The quantity data and tabulation section deal with the quantity data required for different element types and explains how the elements must be modeled and what data must be defined for them so that the necessary data are transmitted to the element drawing. (Betoniteollisuus ry, 2016)

4.6 Modelling casting equipment and producing tables

The modeling and tabulation section covers the modeling of reinforcements and other parts that enter the elements, as well as the marking of associated information so that the appropriate information appears in the element designs' accessories list. Casting equipment is added to concrete elements in such a way that a list of all of the equipment for the element may be created, complete with the right information and units. If it is determined throughout the project that not all components will be modeled, the instructions will explain how to record this information so that the components, as well as the modeled components, will appear in the components' accessories list. (Betoniteollisuus ry, 2016)

4.7 Electrical equipment for the elements

The electrical equipment for the elements section explains how to proceed with the marking of electrical supplies on the element if the electrical designer makes them as 2D drawings and how the electrical drawing is attached back to the model and element drawing. If the structural designer models the electrical accessories in the elements according to the electrical designer’s drawings, the instructions explain what tools are used for modeling and what information is given to the electrical accessories in the model so that the information appears correctly in the element drawing supplies list. (Betoniteollisuus ry, 2016)

4.8 Designing hole reservation based on the information model

The data model-based hole reservation planning section deals with the modeling of hole reservations in elements. The guide discusses the information about the model when the structural designer sends the model to the MEP designer for marking hole reservations. The MEP designer is instructed on how to model the hole reservations and how to act if making a hole is structurally impossible. The guide also explains what things needs to be considered in the process of making hole drawings and what are the different options for implementing it. (Betoniteollisuus ry, 2016)

4.9 Annotations for design status and date

The designer, production, distribution, and installation of the elements that may be utilized in long-term projects are all covered in this area. Elements in long-term projects may have varying design states. While additional elements of the project are still being created, the project may be half completed and in use. With the needed date labels, it must be possible to determine the model's publishing date and the elements' design progress at various stages. It must also be feasible to establish when the model was first published. As a result, it is critical to include all of the features in the model. (Betoniteollisuus ry, 2016)

4.10 Drawings

This section discusses the information required in the generated drawings so that the precast fabrication industry can understand the details of the element. Some of the important information to include in the drawings are the overall 3D view of the element, important views and sections, details, important measurements, reinforcement bar list, design input information, product information, element ID, embed list, etc. (Betoniteollisuus ry, 2016)

5 PRECAST WALL ELEMENT MODELLING IN TEKLA STRUCTURES

Tekla structures 2020 was used to create the model. The following steps were carried out while modelling the element.

5.1 Adding reference model

Usually, when constructing the structural model, the architect’s DWG or IFC files are used as the reference model. The reference model was added by clicking the “Reference models” icon which was on the right side of the window as shown in Figure 2.

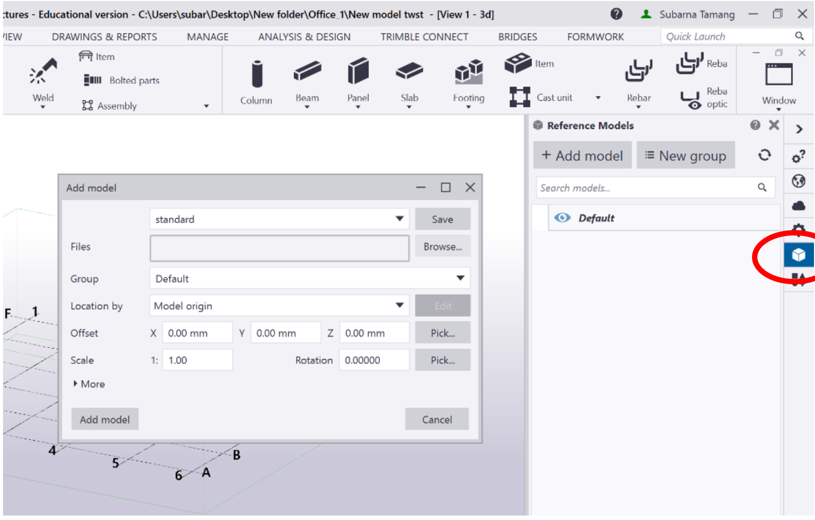


Figure 2. Reference model tab

While adding the reference model, the location and scale can be defined. The imported reference model can be seen in Figure 3.

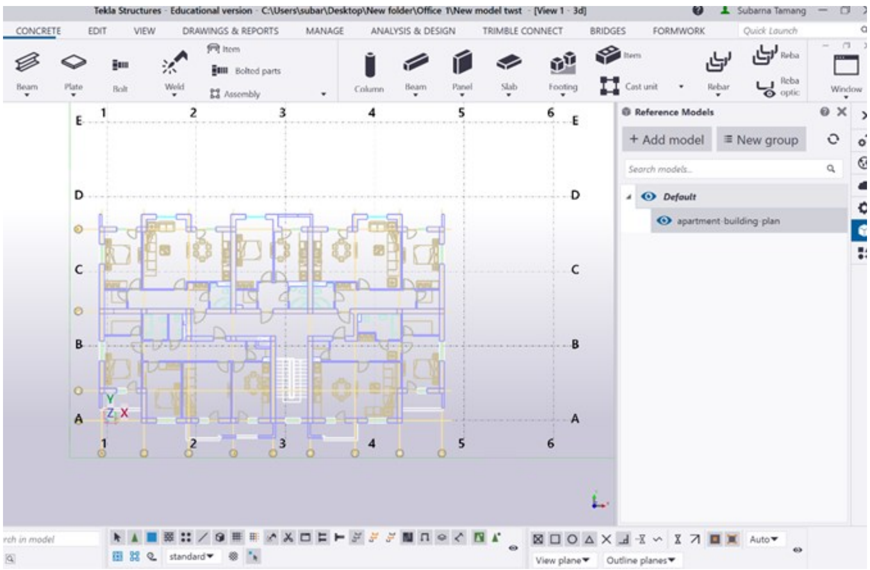


Figure 3. Importing a reference wall layout

After inserting the reference model, which was the floor plan of the building, the grid lines were arranged. The grid lines of the reference model were not aligned to the actual grid lines. We needed to align the grid line of the reference model to the actual grid line. The grid was selected by double-clicking it and the values of the coordinated were given as shown in Figure 4. The values of the coordinates were measured from the reference model. After changing the values of the coordinates, the grid lines were aligned together.

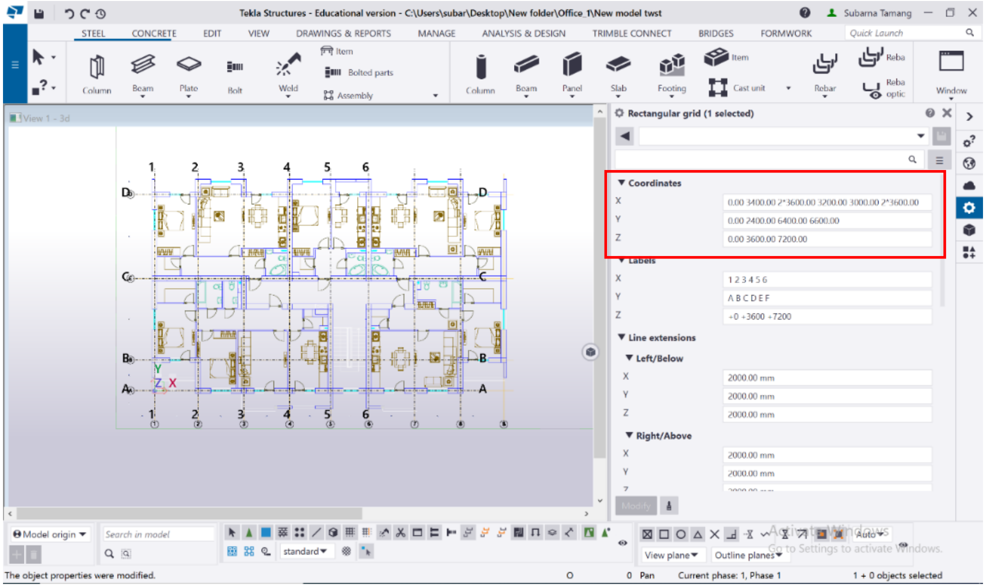


Figure 4. Changing grid lines coordinates

5.2 Creating a wall layout

The wall layout was created by clicking the “Panel” under the “CONCRETE” tab as shown in Figure 5. After that, the wall layout was chosen, and a wall was created along the grid line A.

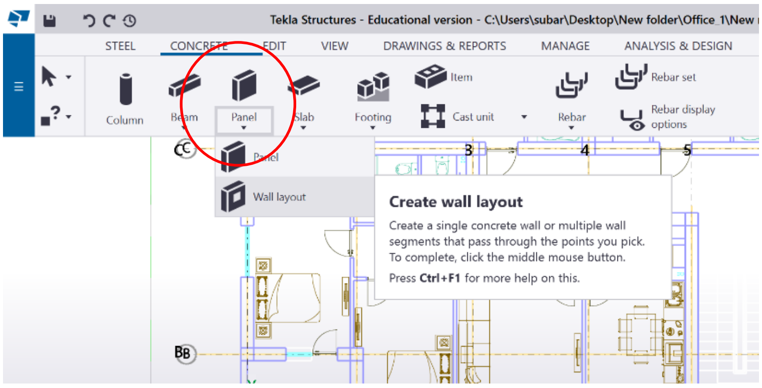


Figure 5. Concrete Wall layout tab

After creating the wall layout, the properties of the wall layout were defined. The sandwich element was selected from the scroll down menu as shown in Figure 6.

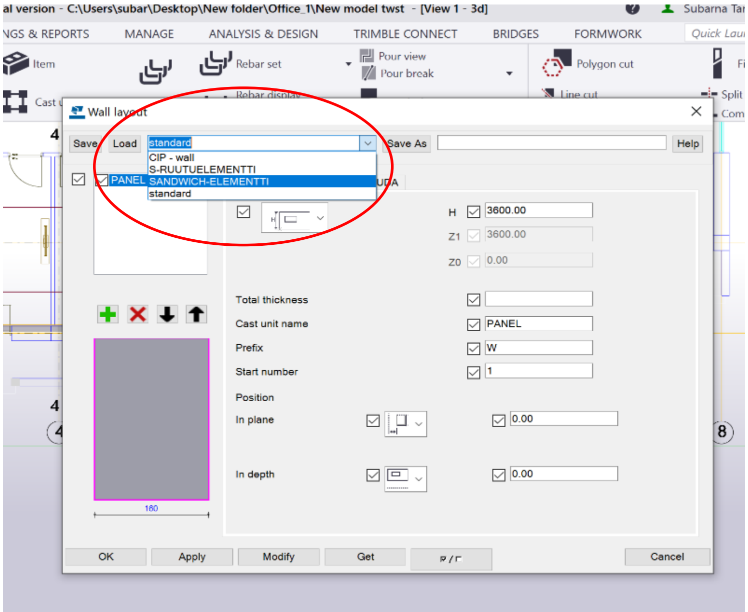


Figure 6. Wall layout setting

The width and height of the sandwich panel were also defined as shown in Figure 7. The total height of 3000 mm and the total width of 450mm were given. The width of inner leaf concrete was 150mm, insulation was 220mm and outer leaf concrete was 80 mm.

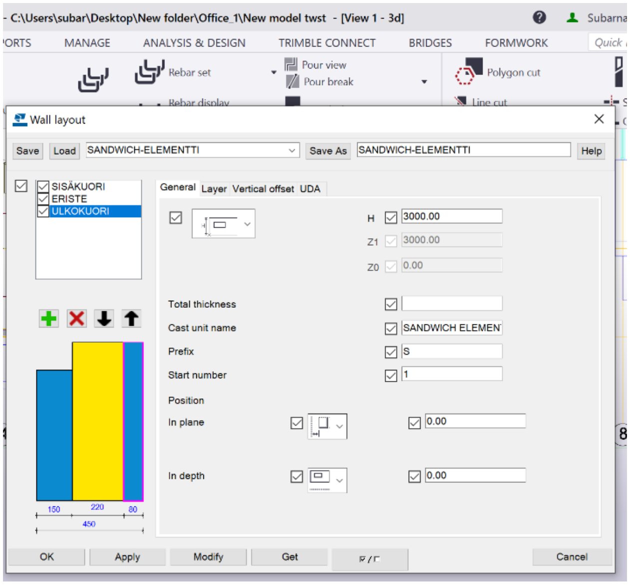


Figure 7. Sandwich panel setting dialog box

The material for the inner and outer leaf were chosen from the “Layer” tab. The concrete class of C30/37 was chosen as shown in Figure 8. The design guide produced by Betoniteollisuus ry recommends different concrete strengths when designing the products. The strength class for the sandwich panel is recommended as C30/37.

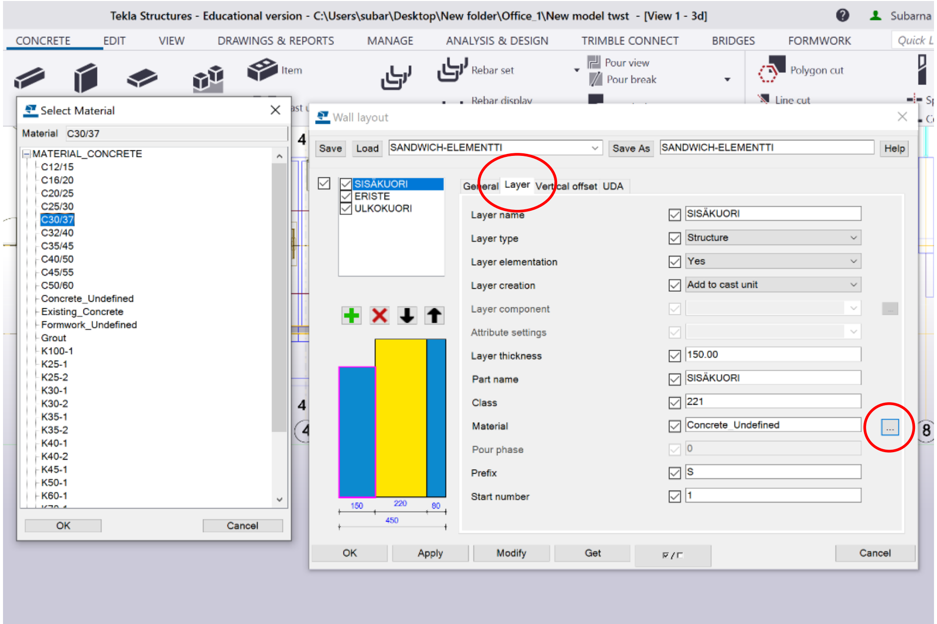


Figure 8. Wall layout layer dialog box

Similarly, the material for the insulation was also chosen. Usually, the production factory chooses the material for the insulation whereas the modeler gives the dimension for it. In the example, EPS60S was chosen. Other properties such as layer thickness, class, part name, etc. can be modified from the dialog box shown in Figure 9.

Also, the Figure 9 shows the "Layer" tab, which defines the Prefix and start number associated with the element numbering and defines the element type.

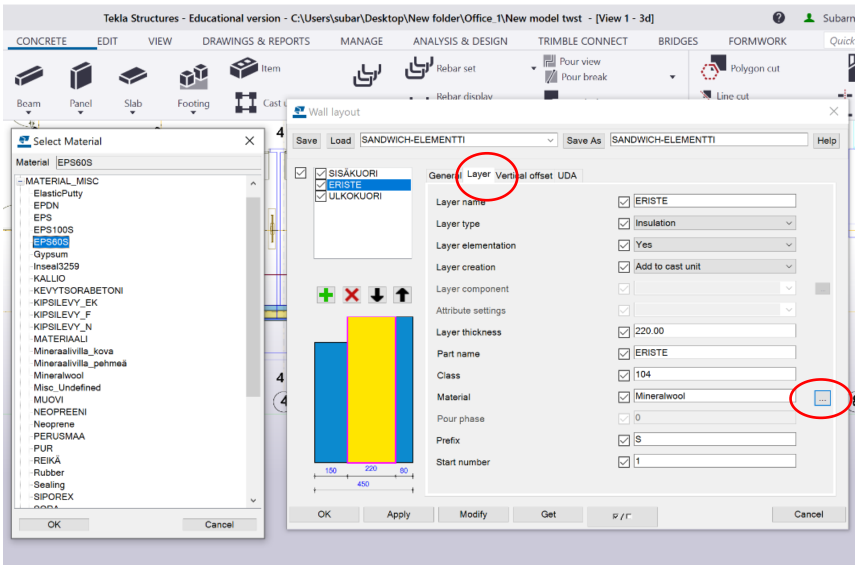


Figure 9. Wall layout layer tab

5.3 Wall layout seam

When the wall layout was created, it was a single piece of precast wall. To break the wall layout into two or more precast wall pieces, wall layout seam was used. Direct modification (D) was turned on by clicking the "Direct modification" switch as shown in Figure 10.

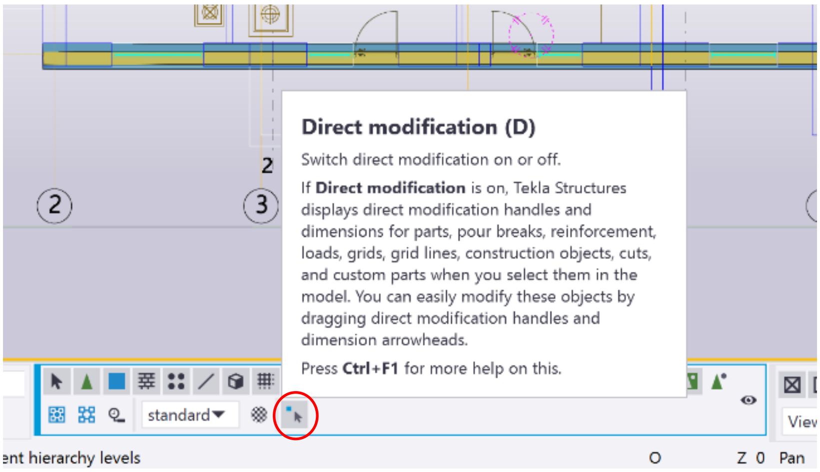


Figure 10. Direct Modification switch

After turning the direct modification on, the wall element was selected, and the contextual toolbar was displayed as shown in Figure 11. Then the wall was modified by selecting the appropriate command from the toolbar which was the "Modify seams" command.

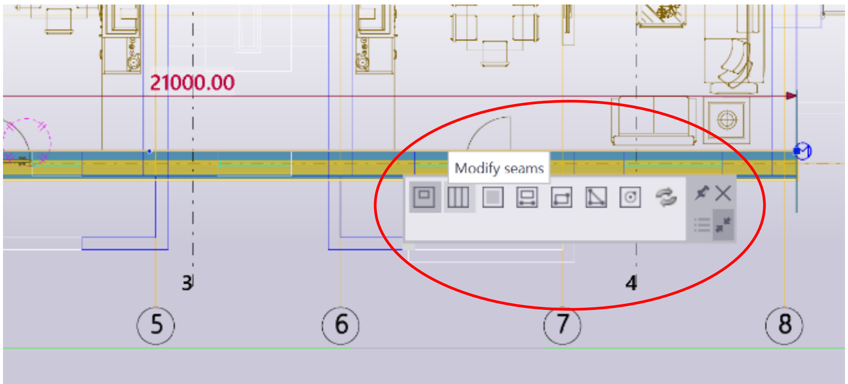


Figure 11. Direct modification contextual toolbar

"Modify seams" was selected from the toolbar and the wall layout seam dialog box was popped. The seam gap of 20mm was defined. The main reason to define the seam gap is due to the thermal expansion and contraction properties of concrete which means the concrete expands slightly as the temperature rises and contracts as temperature falls. Thus, it is important to give some seam gap between the concrete elements. Then the wall element was divided into the required length of the wall panel which was 7440 mm. The recommended maximum length for precast wall panels is 8 m due to transportation and installation reason. The connection component also can be defined from the dialog box if needed. In the example, the connections were kept separately.

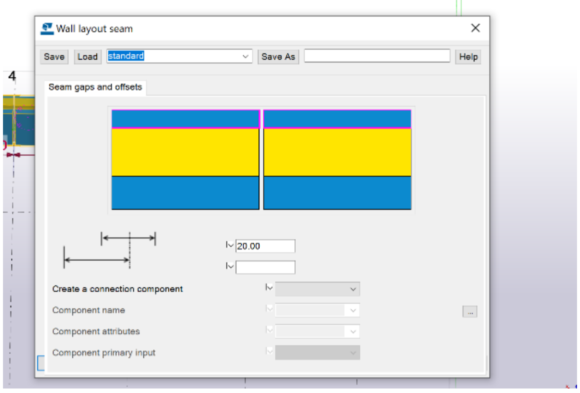


Figure 12. Wall layout seam dialog box

The maximum dimensions of the sandwich elements are determined by the restrictions imposed by the manufacture, transport, and installation. Maximum dimensions may vary from factory to factory. The maximum permissible height in normal transport route is usually between 3600-4200 mm. Higher elements require special transport and the so-called air turning, which is a special lift, as well as the installation plan of the elements must be taken into the account. The lifting equipment on site limits the maximum weight of the element to approx. 10 ton. (Elementtisuunnittelu, n.d.)

5.4 Door and windows openings

Window and door openings were created in the wall element by selecting the "Wall layout opening" tool from the direct modification contextual toolbar. Figure 13 shows how the width and height of the openings were determined. The height of the sill and the positioning of the openings from the respective wall's corner were also defined. For the window, the dimension was 1620*1220 mm and for the door, the dimension was 1020*2220 mm.

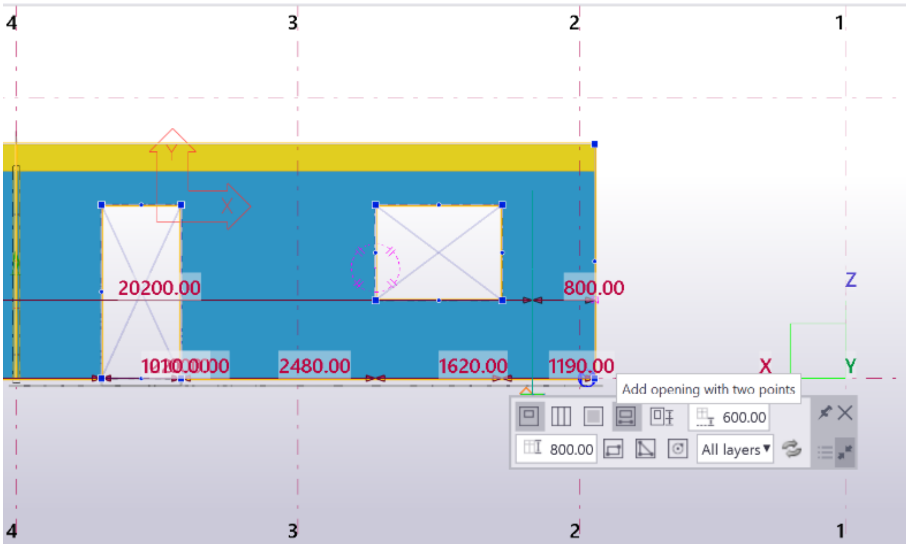


Figure 13. Window and door opening

5.5 Window and door frame

After creating the window and door opening, wooden frame which is also known as "Karmipuu" in Finnish were installed around the openings. Usually, the company has its own custom components, and they are ready to install in the model. But in our case, the frame was built manually.

To create a frame, a "Beam" was chosen from the steel tab. The name Window frame was given, the profile of BL 175*50 was chosen, and timber was chosen as material as shown in Figure 14. The wooden beam frame was placed on top of insulation all around the opening. Similarly, the door frame was also created using the same properties as shown in Figure 15.

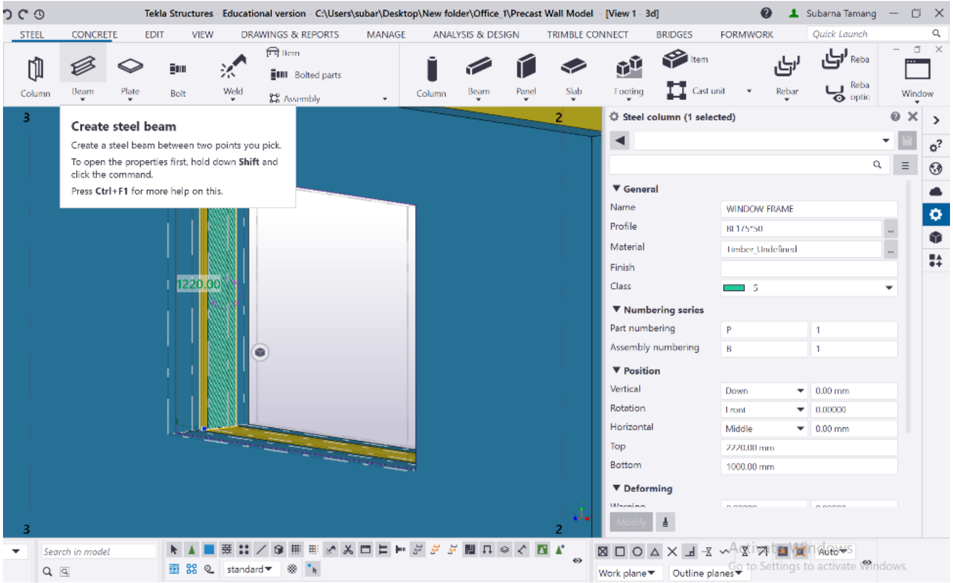


Figure 14. Window frame properties

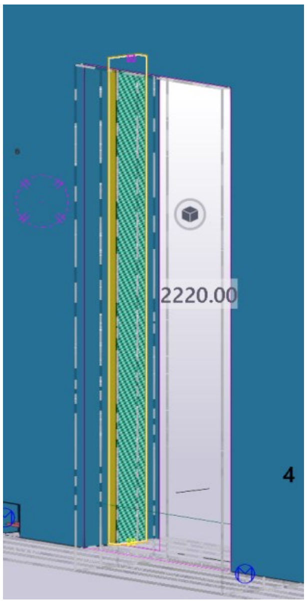


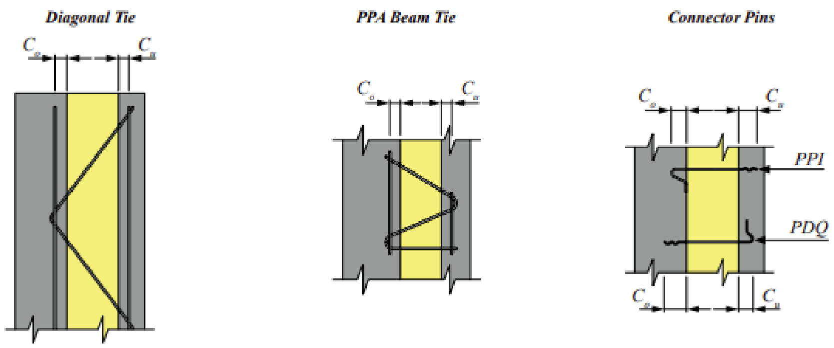
Figure 15. Creating a door frame

5.6 PD diagonal tie - connectors for precast sandwich panels

PD Diagonal Ties and connector pins are single lattice girders that are used to link the inner and outer concrete layers of a sandwich panel together. The diagonals of the connecting ties are made up of stainless steel whereas stainless steel or reinforcing steel are used to make the flanges. The flange material builds upon the exposure class and concrete cover of the flanges. There are four forms of the connector available in several standard models according to the precast panel thicknesses. The types of connectors available in the market are Diagonal Tie, PPA Beam Tie, PPI Connector Pin, and PDQ Connector Pin. (Peikko, 2021)

5.6.1 Choosing of tie and connectors

In our case, we used PD Diagonal tie and PPA Beam tie on top of the openings where the height is insufficient. In Figure 16, we can see the minimum anchorage depth and minimum concrete grade for these ties and connector pins to provide proper functioning. For the concrete grade of C30/37 which was the grade of the concrete we used in our modelling, the anchorage depth for diagonal tie should be a minimum of 25 mm and for PPA Beam tie should be at least 30mm.

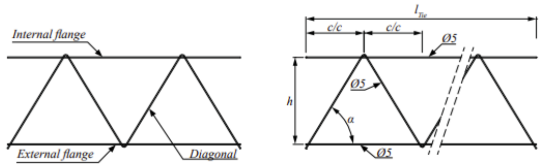


Type of connector	Anchorage depth (c_o/c_u)	Minimum concrete grade (Anchorage point of view)
Diagonal Tie	≥ 25/25	≥ C20/25*
PPA Beam Tie	≥ 30/30	≥ C20/25
PPI Connector Pin	≥ 40/50	≥ C25/30
PDQ Connector Pin	≥ 50/40	≥ C25/30

*Minimum compressive strength of concrete before stripping from the formwork is f_{ck} = 16MPa.

Figure 16. Concrete cover of Ties and Connector Pins with minimum concrete grades (Peikko, 2021)

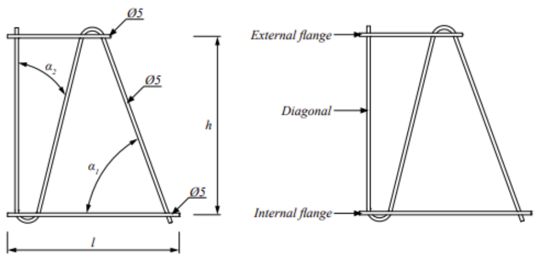
Since the insulation thickness of our model was 220mm, PD 280 was chosen as a diagonal tie from Table 17below whose height was 280 mm, whose length was 2400 mm and c/c was 300 mm.



Diagonal Tie model	h [1]	c/c	Recommended insulation thickness	Length [2]	α	Weight
	[mm]	[mm]	[mm]	[mm]	[deg]	[kg]
PD/PDM/PDR 120	120	300	60	2400	26	1.18
PD/PDM/PDR 140	140		80		29	1.19
PD/PDM/PDR 150	150		90		31	1.20
PD/PDM/PDR 180	180		120		35	1.22
PD/PDM/PDR 200	200		140		38	1.23
PD/PDM/PDR 210	210		150		39	1.27
PD/PDM/PDR 220	220		160		40	1.27
PD/PDM/PDR 240	240		180		42	1.27
PD/PDM/PDR 260	260		200		44	1.28
PD/PDM/PDR 280	280		220		46	1.30
PD/PDM/PDR 300	300		240		48	1.32
PD/PDM/PDR 320	320		260		50	1.34
PD/PDM/PDR 340	340		280		52	1.36
PD/PDM/PDR 360	360		300		53	1.38
PD/PDM/PDR 380	380		320		55	1.40
PD/PDM/PDR 400	400		340		56	1.42

Figure 17. Dimension of diagonal tie (Peikko, 2021)

Similarly, for PPA Beam tie, PPA 280 was chosen from Figure 18 below the height of which was 280 mm and the length was 250 mm.



Beam Tie model	h	l	Recommended insulation thickness	α_1	α_2	Weight
	[mm]	[mm]	[mm]	[deg]	[deg]	[kg]
PPA 150	150	250	90	59	23	0.16
PPA 180	180		120	63	20	0.17
PPA 200	200		140	65	18	0.18
PPA 210	210		150	66	17	0.18
PPA 220	220		160	67	16	0.19
PPA 240	240		180	69	15	0.20
PPA 260	260		200	70	14	0.21
PPA 280	280		220	71	13	0.21
PPA 300	300	300	240	67	15	0.24
PPA 320	320		260	68	14	0.25
PPA 340	340		280	69	13	0.25
PPA 360	360	350	300	65	14	0.28
PPA 380	380		320	66	13	0.28
PPA 400	400		340	67	13	0.29

Figure 18. Dimensions of PPA Beam Tie (Peikko, 2021)

5.6.2 Placement of the ties in the panel

For the position of the ties within the panel, the horizontal edge distance R (see figure 19) must be between 100 and 300 mm. The vertical distance V (see Figure 18) from the upper and bottom edges should be greater than or equal to $c_{min,dur}$ and should be less than or equal to 200 mm, where $c_{min,dur}$ is set in step with EN 1992-1-1. To simplify assembly and minimize wastage, c/c spacing of the ties is usually identical. The recommended c/c spacing is between 100 and 600 mm. It is recommended to use two ties to eliminate the danger of the column buckling (see Figure 17) in narrow spaces like columns (width of column zone 300 – 600 mm). The spacing rules for PPA Beam ties resemble those of Diagonal Ties. (Peikko, 2021)

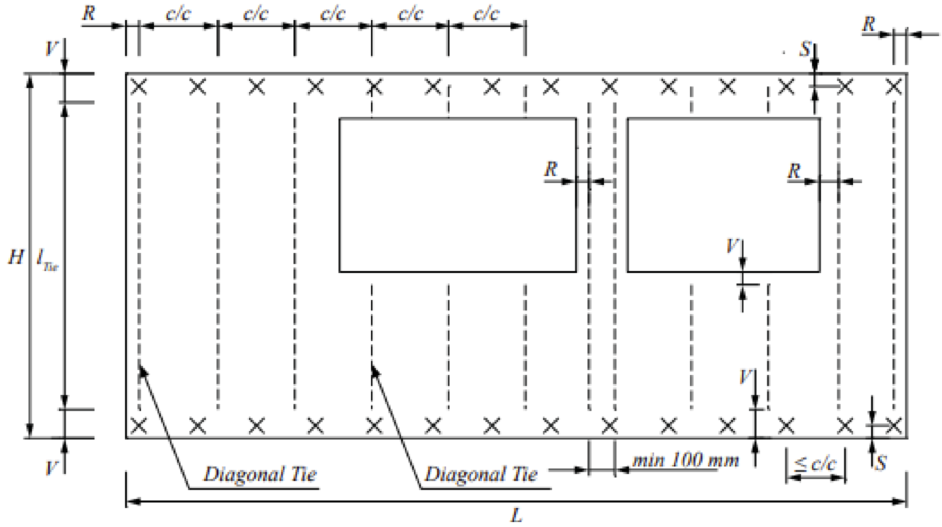


Figure 19. Placement of ties in the panel (Peikko, 2021)

5.6.3 Creating a diagonal tie and beam tie

To create the diagonal tie, a work plane was created on the model by clicking the “Work plane” under the “View” tab as shown in Figure 20 which makes it easier to work.

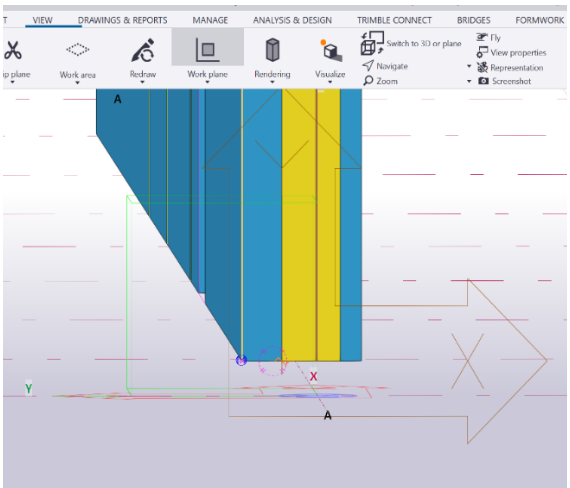


Figure 20. Creating a work plane

After creating a work plane, a “Bar” was selected from the “Rebar” tab as shown in Figure 21.

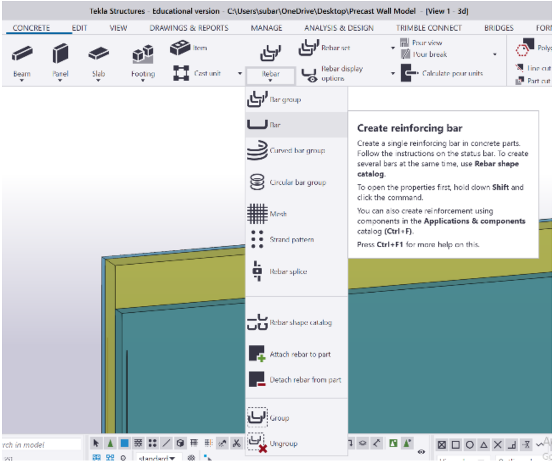


Figure 21. Selecting a bar from the Rebar tab

When the bar was selected, the par to be reinforced was selected, which was the wall in the example. Then single rebar of 2400 mm length was created and placed vertically. Then it was copied along the x-axis at 280mm since the height of the PD diagonal tie was 280 mm. After creating the inner and outer flanges, the diagonal was created with the c/c of 300 mm as shown in Figure 22.

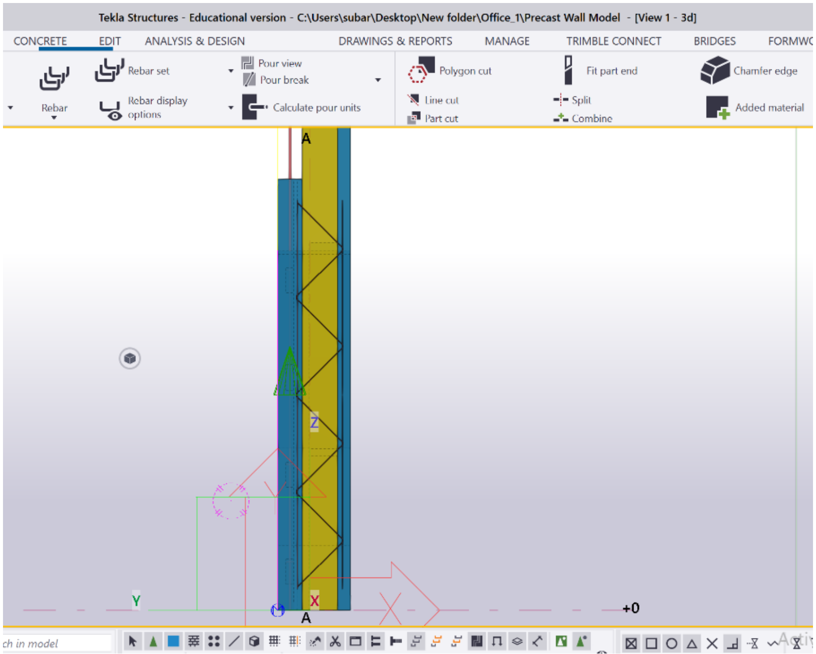


Figure 22. Creating a PD Diagonal Tie

Stainless steel grade of 1.4301 and size of 5mm was chosen as a material for both flange and diagonal. Then it was named PD 280-2400 as shown in Figure 23.

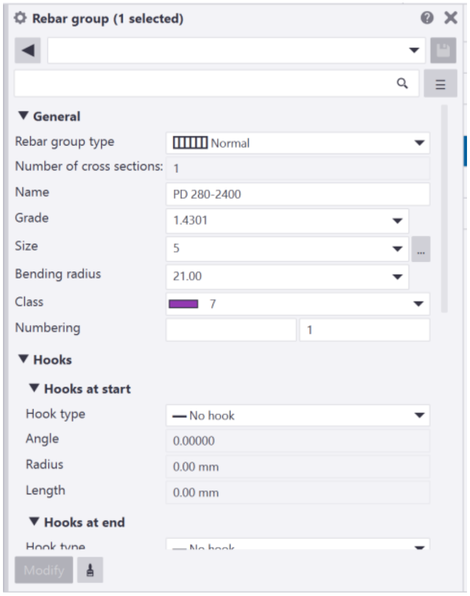


Figure 23. PD Diagonal tie properties

Similarly, the PD diagonal tie of length 600 mm was also created and aligned under the opening of the wall as shown in Figure 24. It was named as PD 280-600. The PD diagonals were placed with a spacing distance of 600 mm on the panel.

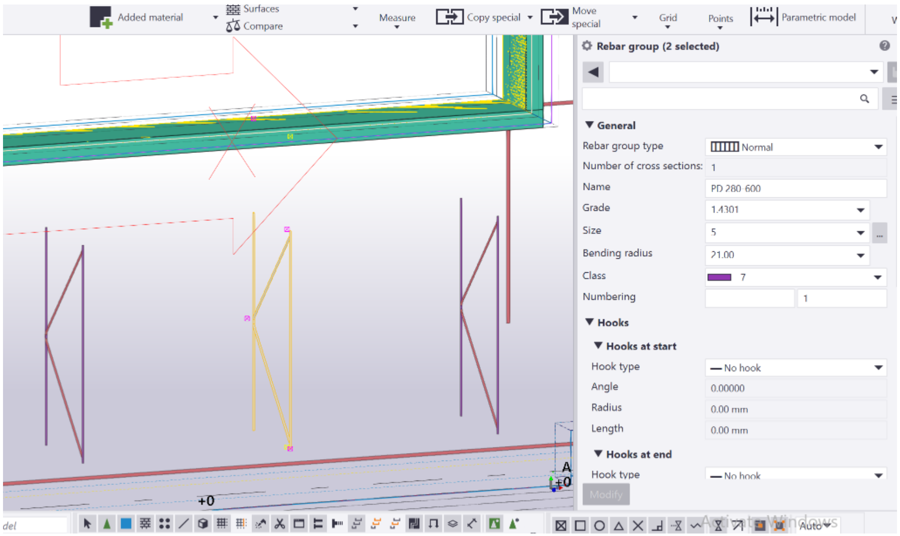


Figure 24. Creating PD Diagonal under the window openings

For the top of openings, PPA Beam Tie was created. The spacing gap between the beam ties was only 300 mm. The length of the beam tie was 250 mm. The same profile was used for the beam tie as of diagonal tie and named as PPA 280 as in Figure 25.

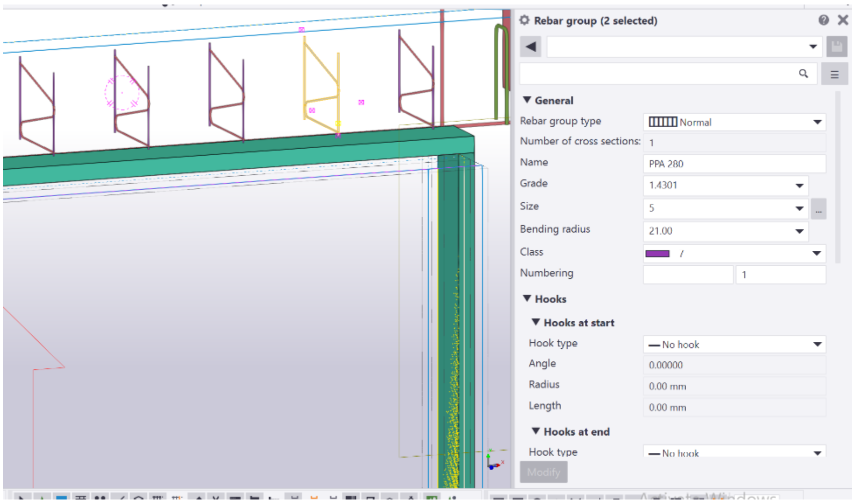


Figure 25. PPA Beam Tie Properties

Figure 26 shows the overall placement of the PD Diagonal and PPA Beam ties placement in the wall panel.

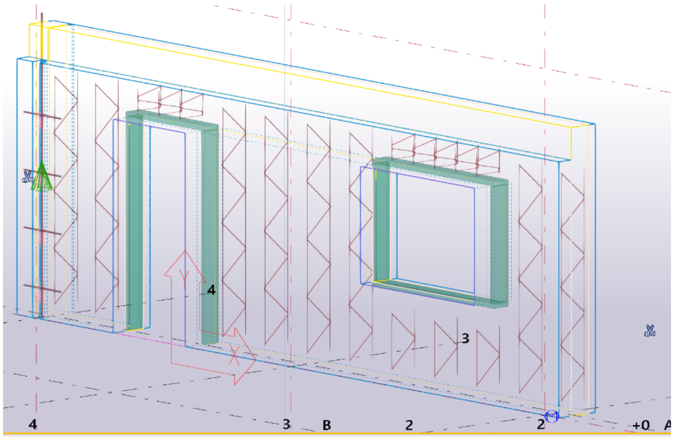


Figure 26. Placement of ties in the model

5.7 Reinforcement of the panel

By reinforcing the concrete with steels, the concrete gains strength and sturdiness. On its own, concrete has a high compressive strength, but it lacks tension and shear strength. When sustaining weights over lengthy periods of time, this might lead to cracking. Steel has a lot of stress and shear strength, which concrete does not have. Steel acts similarly to concrete in changing settings. It shrinks and expands with the concrete, preventing cracks.

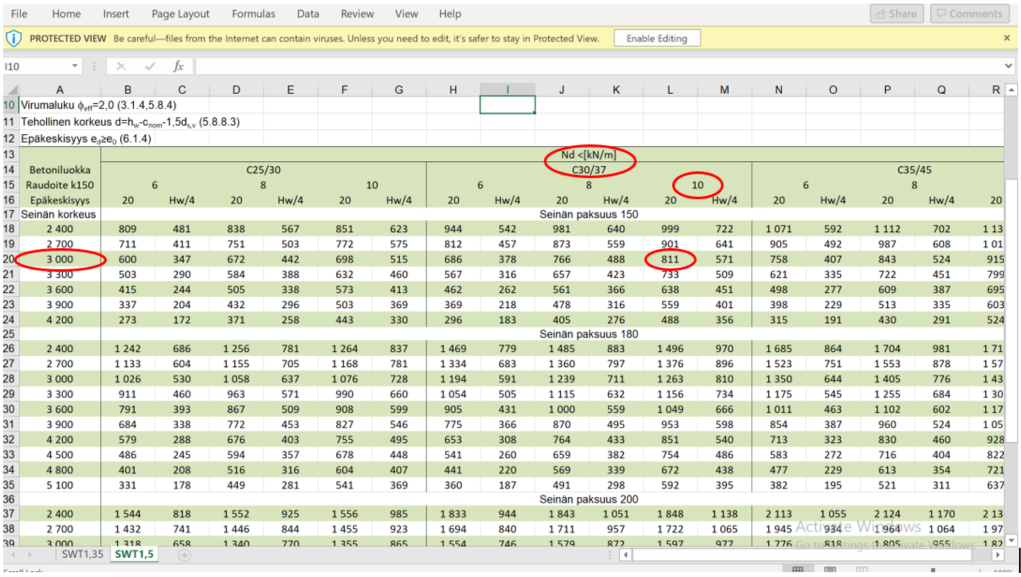
Rebar is one of the most prevalent kinds of concrete reinforcement. Steel rebars are used to produce the reinforcement and are positioned in a certain order inside the panel. Rebars are bendable and may be bent into whatever form. Steel is the most popular material for rebar, though treated steels such as stainless steel, galvanized steel, and epoxy coating are available to prevent corrosion.

5.7.1 Choosing of reinforcement size

While choosing the reinforced bars, the most unfavourable combination of actions should be defined. The design value of the horizontal shear force F_{tot} must be smaller than the design value of the shear resistance of the reinforced bars (capacity of the dowels) F_{VRd}.

$F_{tot} < F_{VRd}$

After all, there was not any real data and load calculation while modelling this element. For the concrete class of C30/37 and the wall height of 3000 mm, T10 was chosen which has the maximum load-bearing capacity of N_d=811 kN/m from the table below.



Virumaluku ϕ_{eff}=2,0 (3.1.4,5.8.4)
Tehollinen korkeus $d=h_w-c_{nom}-1,5d_{s,v}$ (5.8.8.3)
Epäkeskisyys $e_d \geq e_0$ (6.1.4)

	Nd <[kN/m]																
Betoniluokka	C25/30						C30/37						C35/45				
Raudoite k150	6		8		10		6		8		10		6		8		
Epäkeskisyys	20	Hw/4	20	Hw/4	20	Hw/4	20	Hw/4	20	Hw/4	20	Hw/4	20	Hw/4	20	Hw/4	20
Seinän korkeus	Seinän paksuus 150																
2 400	809	481	838	567	851	623	944	542	981	640	999	722	1 071	592	1 112	702	1 13
2 700	711	411	751	503	772	575	812	457	873	559	901	641	905	492	987	608	1 01
3 000	600	347	672	442	698	515	686	378	766	488	811	571	758	407	843	524	915
3 300	503	290	584	388	632	460	567	316	657	423	733	509	621	335	722	451	799
3 600	415	244	505	338	573	413	462	262	561	366	638	451	498	277	609	387	695
3 900	337	204	432	296	503	369	369	218	478	316	559	401	398	229	513	335	603
4 200	273	172	371	258	443	330	296	183	405	276	488	356	315	191	430	291	524
	Seinän paksuus 180																
2 400	1 242	686	1 256	781	1 264	837	1 469	779	1 485	883	1 496	970	1 685	864	1 704	981	1 71
2 700	1 133	604	1 155	705	1 168	781	1 334	683	1 360	797	1 376	896	1 523	751	1 553	878	1 57
3 000	1 026	530	1 058	637	1 076	728	1 194	591	1 239	711	1 263	810	1 350	644	1 405	776	1 43
3 300	911	460	963	571	990	660	1 054	505	1 115	632	1 156	734	1 175	545	1 255	684	1 30
3 600	791	393	867	509	908	599	905	431	1 000	559	1 049	666	1 011	463	1 102	602	1 17
3 900	684	338	772	453	827	546	775	366	870	495	953	598	854	387	960	524	1 05
4 200	579	288	676	403	755	495	653	308	764	433	851	540	713	323	830	460	928
4 500	486	245	594	357	678	448	541	260	659	382	754	486	583	272	716	404	822
4 800	401	208	516	316	604	407	441	220	569	339	672	438	477	229	613	354	721
5 100	331	178	449	281	541	369	360	187	491	298	592	395	382	195	521	311	637
	Seinän paksuus 200																
2 400	1 544	818	1 552	925	1 556	985	1 833	944	1 843	1 051	1 848	1 138	2 113	1 055	2 124	1 170	2 13
2 700	1 432	741	1 446	844	1 455	923	1 694	840	1 711	957	1 722	1 065	1 945	934	1 964	1 064	1 97
3 000	1 318	658	1 340	770	1 355	865	1 554	746	1 579	872	1 597	977	1 776	818	1 805	955	1 82

Figure 27. Rebar sizing excel table (Elementtisuunnittelu, n.d.)

5.7.2 Adding a reinforcement in the model.

To install the wall panel reinforcement, "Wall Panel Reinforcement" was used from the "Applications & components" section as shown in Figure 28.

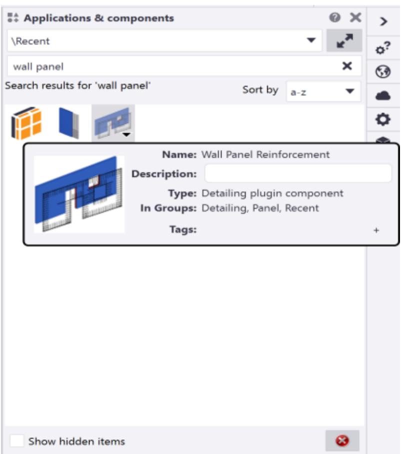


Figure 28. Wall panel reinforcement component

After clicking the wall panel reinforcement, the reinforcing part which was the inner concrete leaf was selected and automatically a reinforcement was created. The properties of the reinforcement can by modified by double-clicking the created one. In the “Picture” tab, the rebar count and concrete cover of 35mm were defined as shown in Figure 29.

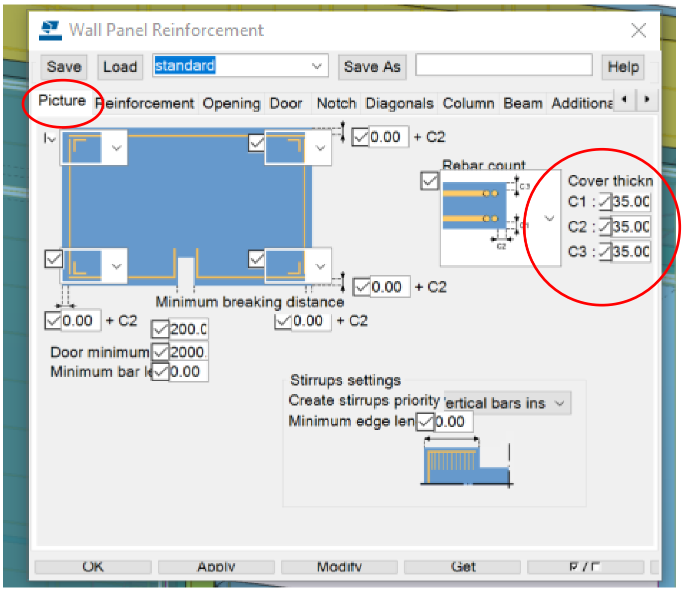


Figure 29. Picture tab of wall panel reinforcement dialog box

Then in the “Reinforcement” tab, the size of the rebar, which was 10 mm, grade of B500B, bending radius of 20 mm and splice length of 600 mm was modified. No mesh was created for the inner leaf. The properties of the “Reinforcement” tab can be seen in Figure 30.

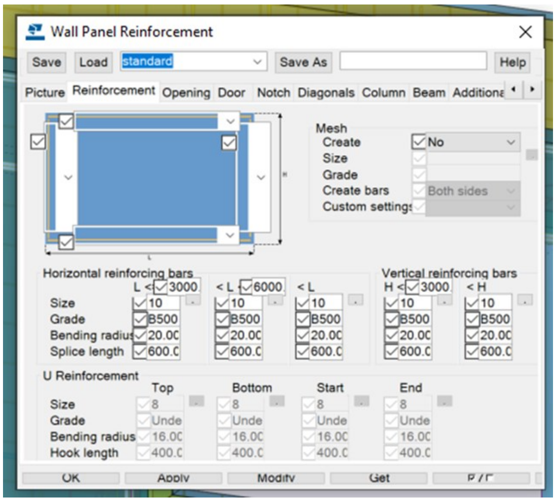


Figure 30. Reinforcement tab of wall panel reinforcement dialog box

In the opening, the size, grade, bending radius and splice length for the horizontal and vertical reinforcing bar were also defined. The properties for the “Opening” tab were also changed as shown in Figure 31 below.

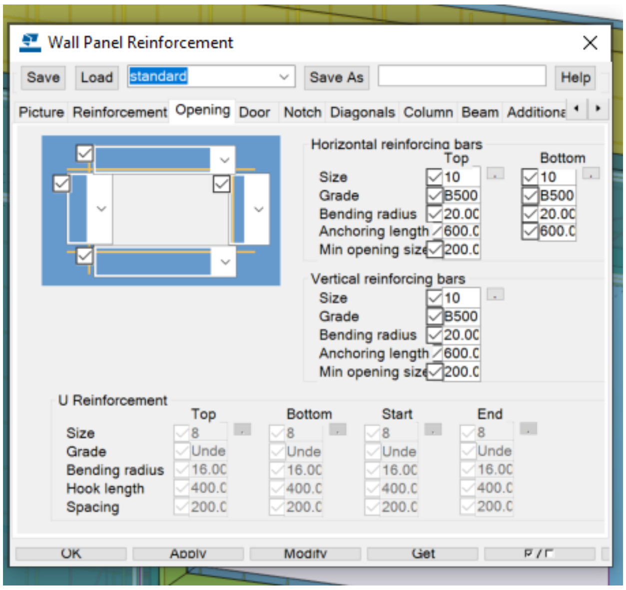


Figure 31. Opening tab of wall panel reinforcement dialog box

In the “Column” tab, the horizontal distance between the door opening and the edge of the wall (B) is more than 1000 mm, so the column was not created. Whereas the height from the top edge of the wall to the opening is less than 1000 mm, a beam was created to prevent cracking. In the “Beam” tab, the maximum beam height and length were defined. The size for the top rebar of the beam was chosen T10 whereas the bottom rebar was T12. Also, T8 was chosen as the size for the stirrup and spacing of 200 were given as shown in Figure 32.

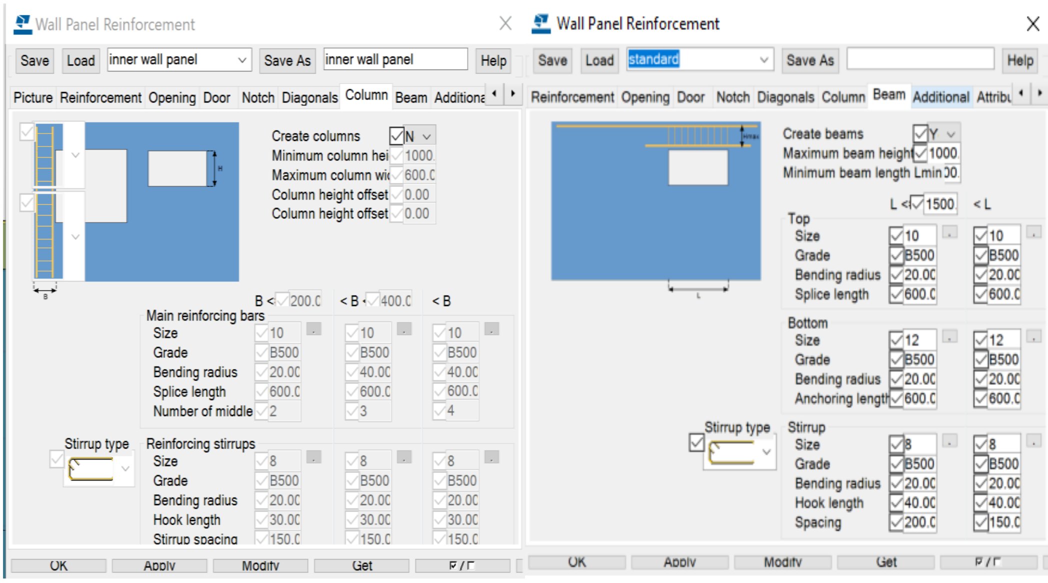


Figure 32. Column and Beam tab of wall panel reinforcement dialog box

In the “Attributes” tab, name, class, prefix and start number were modified as shown in Figure 33 below.

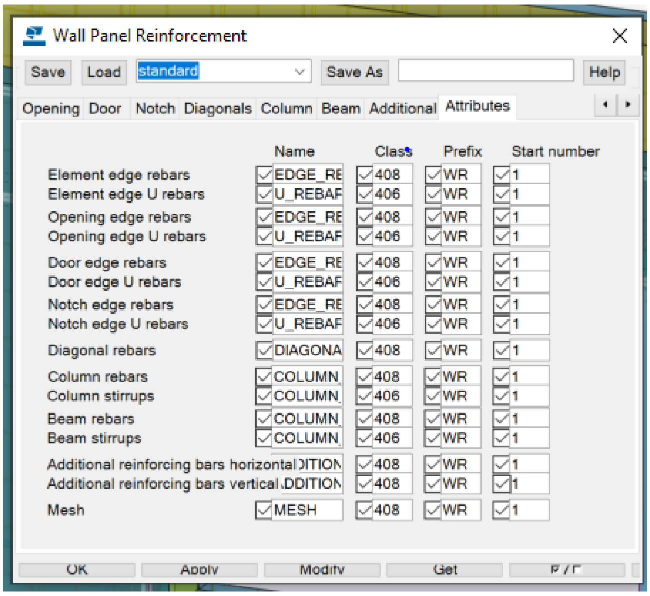


Figure 33. Attributes tab of wall panel reinforcement

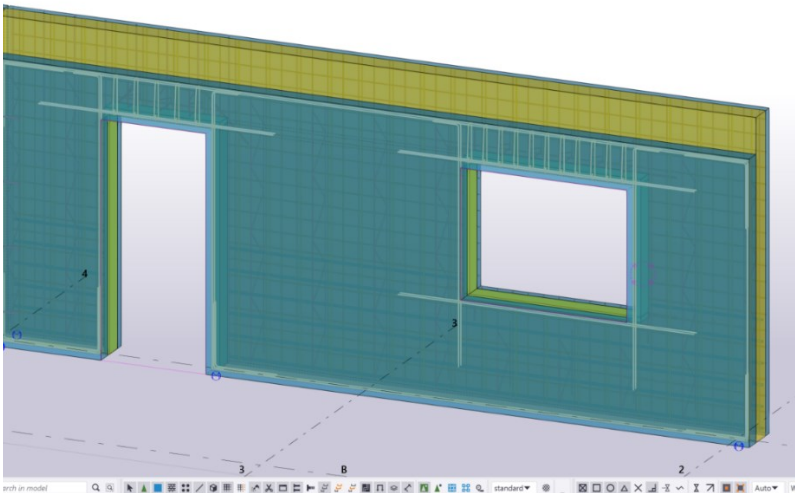


Figure 34. 3D view of the model after creating reinforcement in the inner leaf

Similarly, the outer leaf concrete was also reinforced. The thickness of the outer leaf was only 80mm so, the rebar size of 7 mm was chosen. Stainless steel was chosen as a material because the outer leaf will be exposed to the outside environment and prevents rusting. The properties of the reinforced were also modified. The rebar count and concrete cover of 25mm were defined in the "Picture" tab as shown in Figure 35 below.

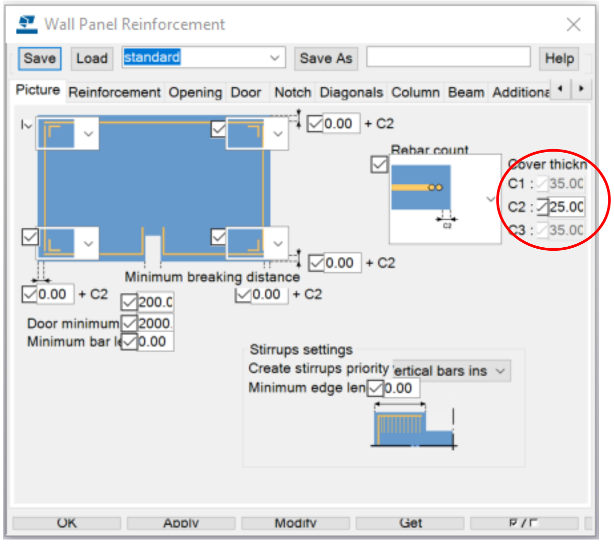


Figure 35. Picture tab of outer wall panel reinforcement

In the “Reinforcement” tab, the mesh was defined. The size of 7mm, grade B500K, bending radius of 20mm and splice length of 600 mm was chosen as shown in the Figure 36 below.

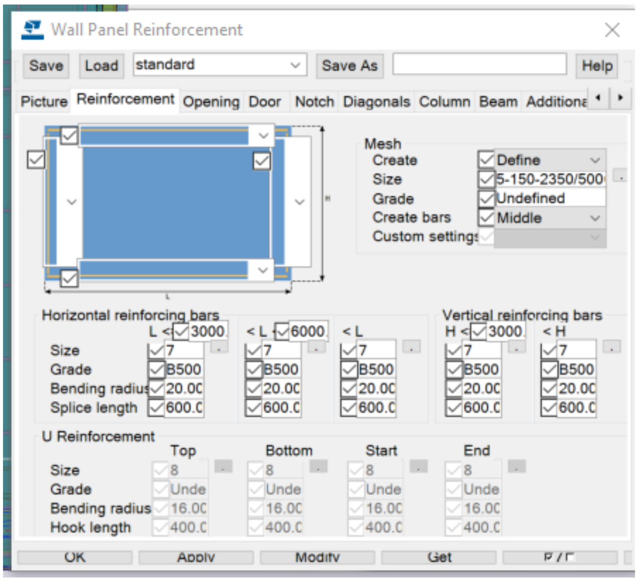


Figure 36. Reinforcement tab of outer wall panel reinforcement.

In the “Opening” and “Door” tab of the reinforcement, the same materials were chosen as in the Figure 37 below.

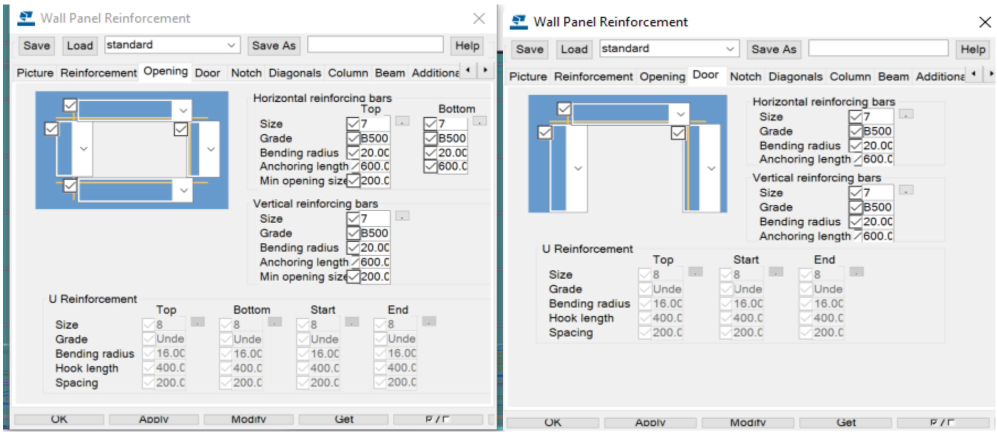


Figure 37. Opening and Door tab of outer layer reinforcement

Beam and column were not created in the outer leaf since the thickness of the leaf was insufficient. The properties for the “Column” and “Beam” tab of wall panel reinforcement can be seen in Figure 38.

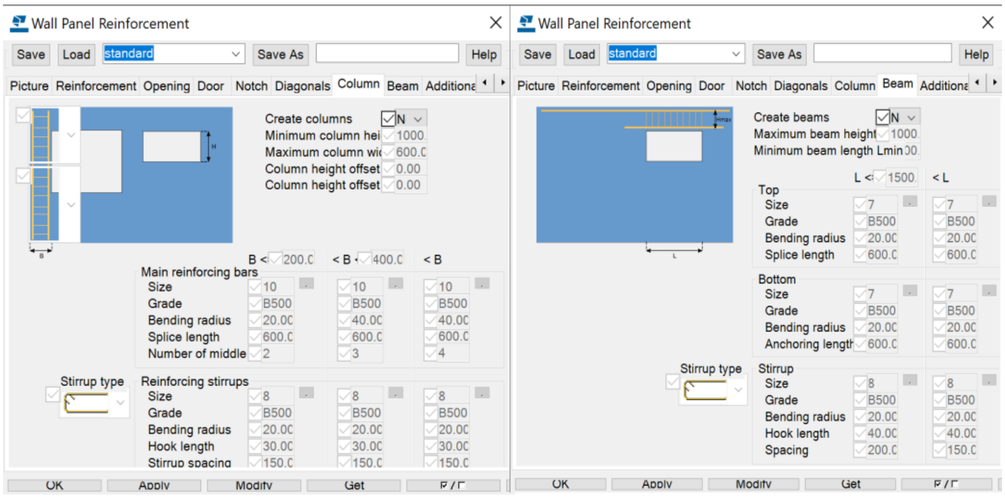


Figure 38. Column and Beam tab of outer layer reinforcement

Mesh properties were modified by simply selecting the mesh from the model. The size, grade and spacing of the rebars were changed according to the needs as shown in Figure 39.

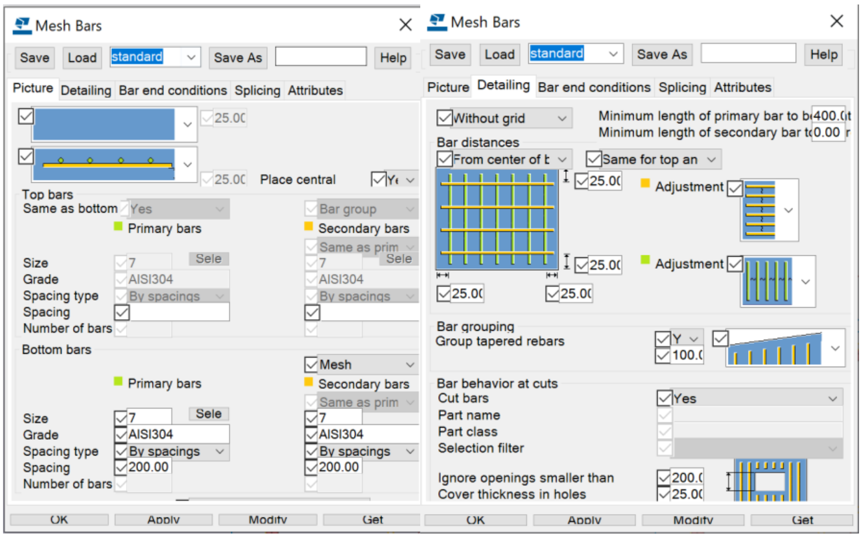


Figure 39. Mesh Properties

5.8 Wall to wall connection

5.8.1 Vertical joints of the wall panel

Wire loops were selected for the vertical joints. In Finland, they are the most widely used.

PVL Connecting Loops are single-wire loops that are used to link precast wall panels to one another or to a column. Before the panel is cast, wire loop boxes are added to the formwork at the appropriate spacing to carry the shear stresses. The protective tape is removed once the formwork is removed, and the loop is then opened with a hammer or a pin. In accordance with the drawings, wall panels are erected and supported. The horizontal location of the loops is confirmed before vertical rebar is put into a joint through the loops. Concrete grout is poured or pumped into the joint once the formwork is completed. (Peikko, n.d.)

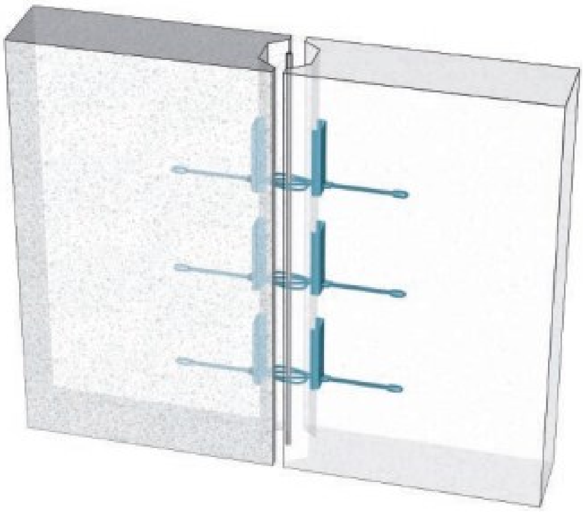


Figure 40. PVL Connecting Loops in the joints of wall panels (Peikko, 2020)

Before installing the PVL connecting loops into the model, the Peikko PVL Connecting Loops UEL package was downloaded from the Tekla Warehouse and was installed in the Tekla Structures.

The type of wall connection to use is determined by the location of the wall. The vertical joint of the wall near the door opening had a straight wall to wall connection to another wall. The vertical connection was created by using the "Wall to wall connection" component. The component can be found by simply searching wall to wall connection in the "Application & components" section as shown in Figure 41 below.

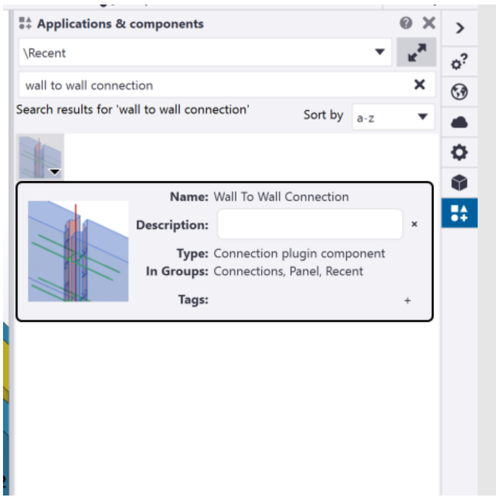


Figure 41. Wall to wall connection

After selecting the connection, the walls were selected, and the connection was created automatically. Then the properties of connection were changed. In the "Edge shape" tab, the size of the edges was selected as per the requirements and the gap between the edges were defined as in Figure 42. The main reason to put the gap between the edges is to pour the concrete in site after the installation which makes the connection steady.

Figure 42. Wall to wall connection edge shape

In the "Connectors" tab, EB_PVL80 was chosen as the connecting loops. One piece of PVL80 connecting loop has a shear resistance of 80kN force. Four pieces of PVL80 were chosen with a spacing distance of 600 mm. The minimum distance of PVL from the bottom of the wall is 100mm. Thus, we choose 300mm from the bottom of the wall. A long bar of size T12 and grade B500B which goes inside the connecting loops was also chosen in the properties as shown in Figure 43.

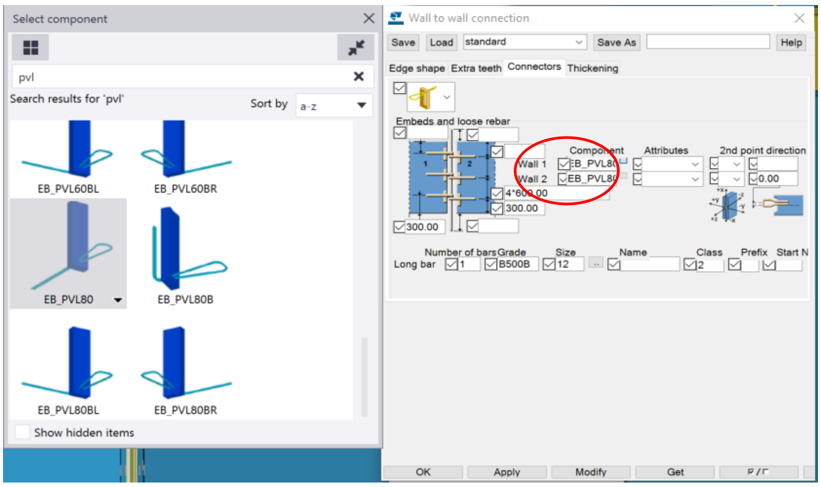


Figure 43. Connectors tab of the wall to wall connection

The properties of the connecting loops can be seen in Figure 44 below.

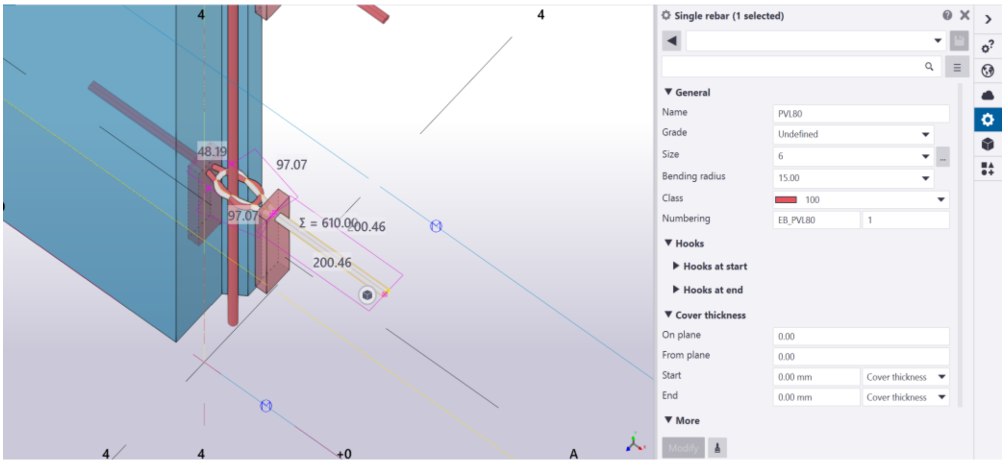


Figure 44. PVL Connecting loops properties

Since the other end of the vertical joint of the wall was perpendicular to the connecting wall so, the wall layout connector tool was used in this case. The “Wall layout connector” was selected from the “Application & components” section. The seam gap was given and “Wall to wall connection” was also chosen in the “Connection” option as shown in Figure 45 below and a connection was created automatically.

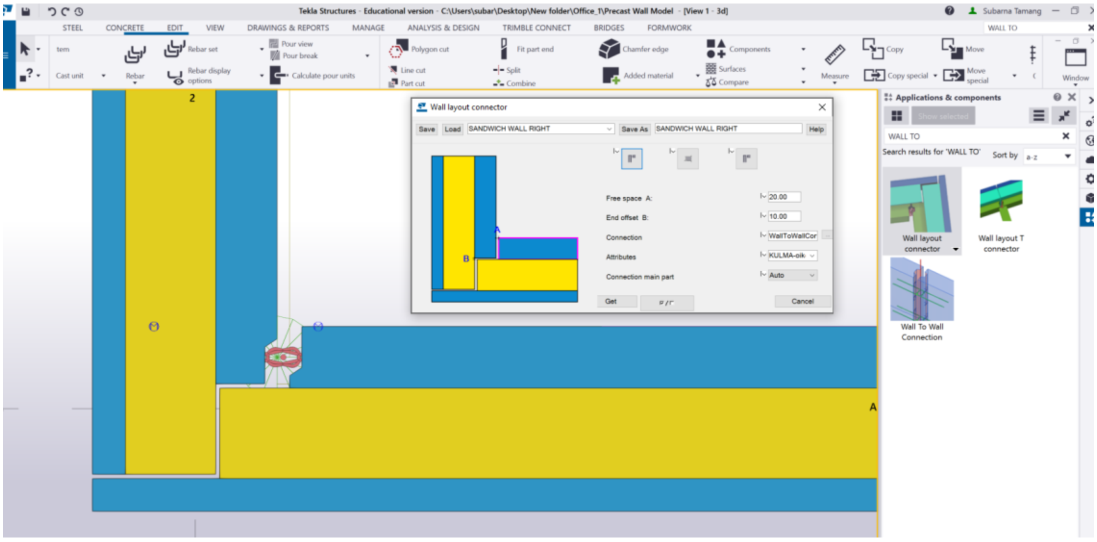


Figure 45. Wall layout connector properties

Then the properties of the connection were also changed similar to the other connection of the wall. The edge shapes were different from the other side but the materials for the connecting loops were the same. The “Edge shape” and the “Connectors” properties can be seen below in Figure 46.

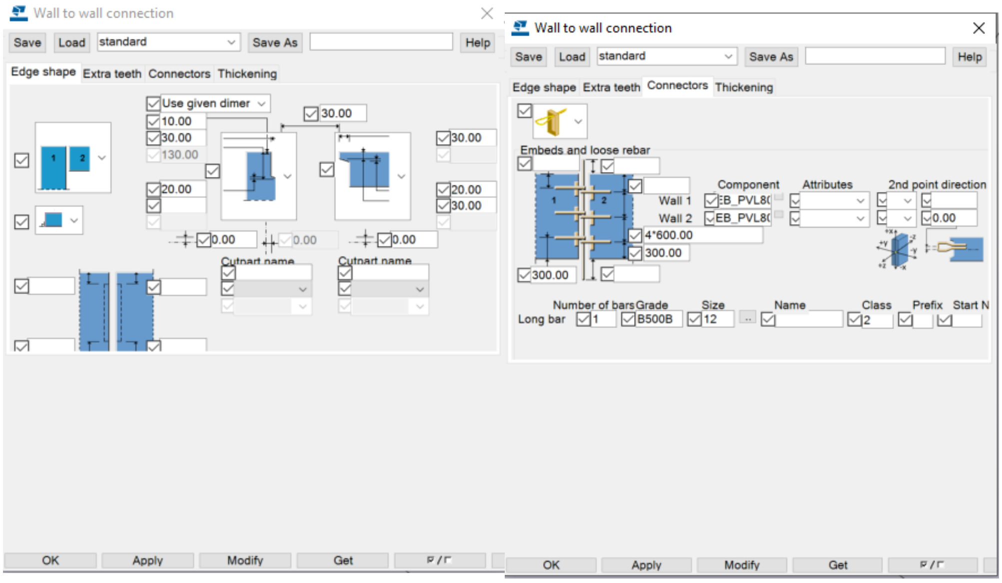


Figure 46. Wall to wall connection properties

5.8.2 Horizontal joints of the wall panel

For the horizontal joints of the wall panel, reinforced bars were used. Steel bars are partially embedded in this sort of joint. They serve as a dowel in the horizontal joint, transferring shear strain. Precast walls in Finland typically employ this type of connection for the horizontal joints.

This sort of connection also has a number of failure models. They are determined by the steel bar's strength and size, as well as its position relative to the element boundaries. The shear of a weak bar in a particularly powerful concrete part might cause the bar to fail. A strong steel bar in a very weak element, especially one with a little concrete cover, will more naturally cause the element to fracture. As a result, it is critical to select the right rebar size, grade, and placement.

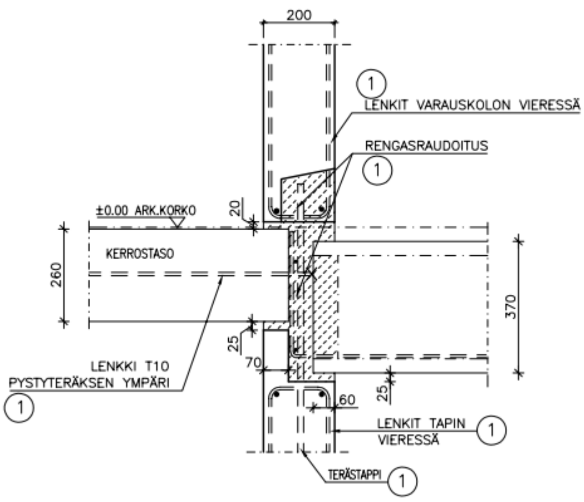


Figure 47. Reinforced bar joint (Elementtisuunnittelu/liitokset, n.d.)

For the top horizontal joints of the wall panel, Rebar connections were created manually in the model since there was not any custom component. A reinforcing bar of size T16 and grade B500B was created in the inner leaf of the wall. The height of the bar was 1020 mm where 500mm of the bar was inside the inner leaf of the wall as shown in Figure 48.

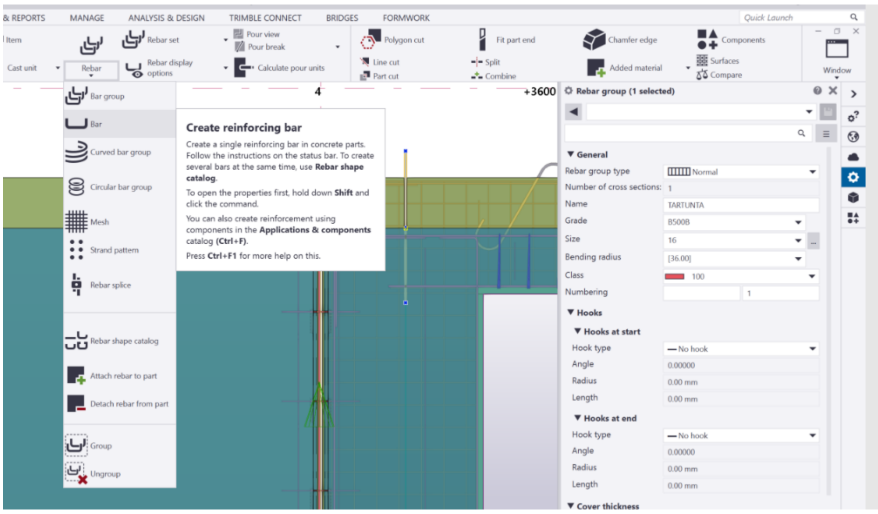


Figure 48. Creating a rebar connection

The created rebar was copied and placed in the wall panel as shown in Figure 49 below.

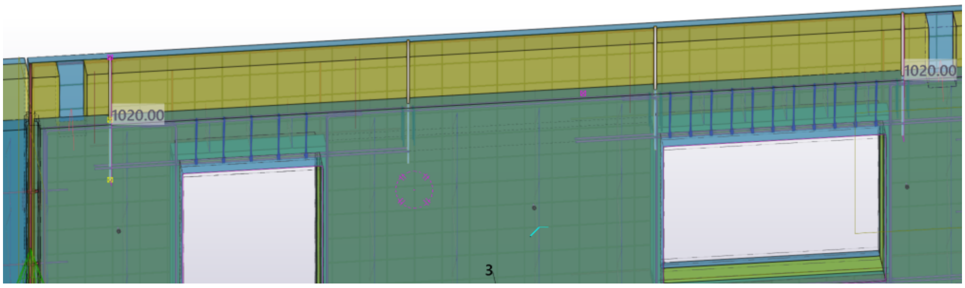


Figure 49. Alignment of rebar connection

Then a couple of U-shape rebars facing downward were also installed on both sides of the rebar to make the connection more steady and stronger as in Figure 50. The gap between the U-shape rebars was given as 80 mm.

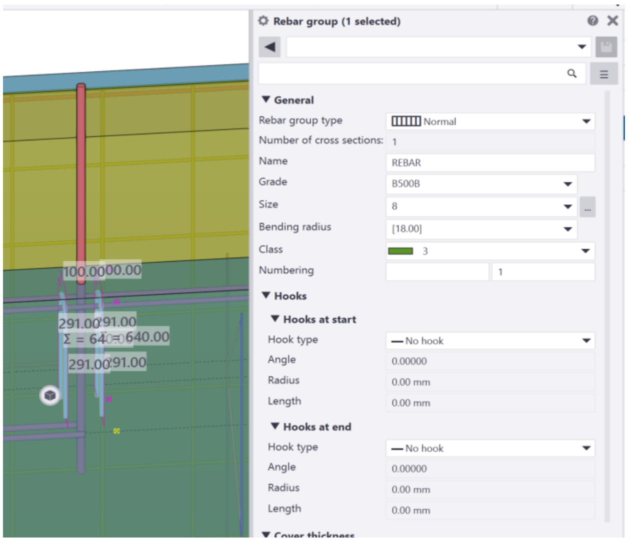


Figure 50. U-shape rebar properties

For the bottom horizontal joints of the wall, holes of 150*150*120 were made. The holes were made by creating a concrete beam of size 150*150*120 and were placed in the inner concrete leaf as shown in Figure 51 below. Then the “Part cut” tool was used to cut the hole and the beam was deleted after cutting the part.

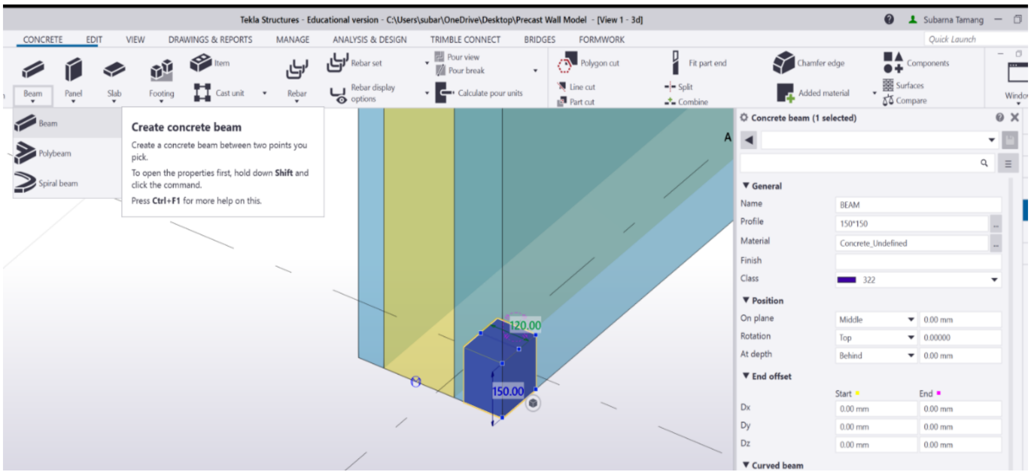


Figure 51. Creating a beam for hole

After creating the hole, the holes were copied and aligned accordingly as shown in Figure 52. All the holes were aligned perpendicular to the rebar connection. And similarly, the U-shaped rebars were also installed around the hole at a distance of 200 mm.

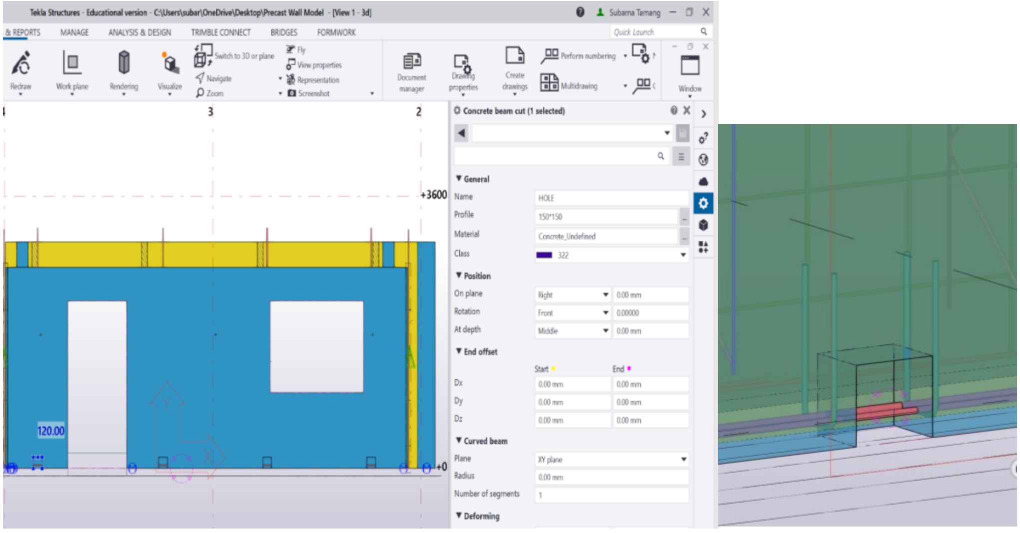
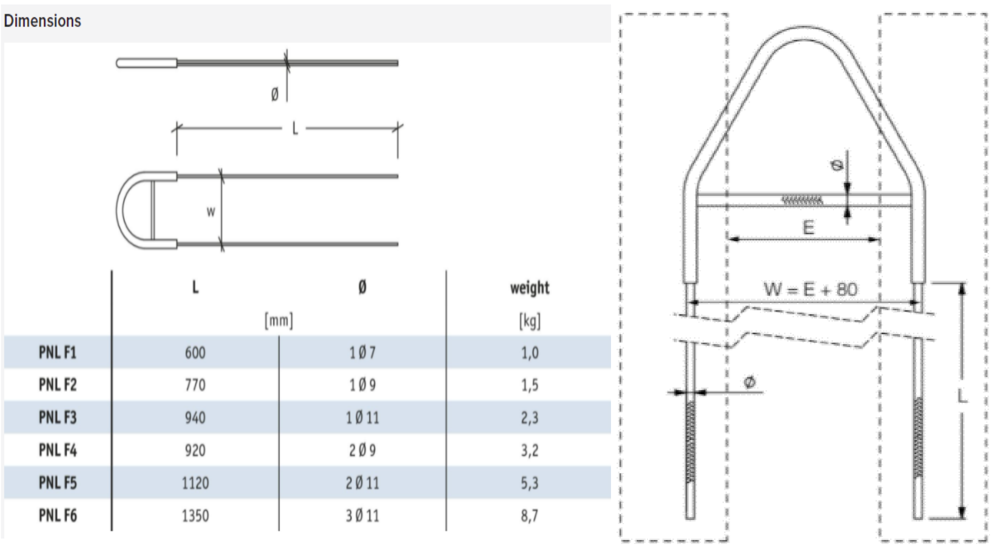


Figure 52. Placement of the holes and U-shape rebar

5.9 Lifting inserts

Lifting inserts are designed to lift the precast element. PNLF Sandwich Wall Insert was chosen as the lifting insert for our element.

The anchoring of PNLF Sandwich Wall Inserts is based on the inserts' own anchoring rebars, which are permanently cast into the inner and outer panels of sandwich walls. They are built perpendicular to the angular pull, with a maximum load angle of 30 degrees. Because PNLFs are made of stainless steel, they are an excellent choice for sandwich wall outer panels. They are a cost-effective option that eliminates the need for specific lifting keys because the lifting slings may be attached directly to the PNLF Insert. (Peikko, n.d.)



	L	Ø	weight
	[mm]		[kg]
PNL F1	600	1 Ø 7	1,0
PNL F2	770	1 Ø 9	1,5
PNL F3	940	1 Ø 11	2,3
PNL F4	920	2 Ø 9	3,2
PNL F5	1120	2 Ø 11	5,3
PNL F6	1350	3 Ø 11	8,7

Figure 53. PNLF types (Peikko, n.d.)

When the thickness of the insulation (E) is greater than 200 mm, then the PNLF is produced as a triangle shape. In our case, the thickness of the insulation was 220 mm so, the PNLF used in the model is in a triangular shape. The dimension (W) is the thickness of the insulation layer + 80 mm which in our case was (220+80) mm i.e., 300 mm.

The plugin for the Lifting inserts was downloaded from the Tekla Warehouse. The “Lifting Inserts” was selected from the “Application & components” section as shown in Figure 54 below.

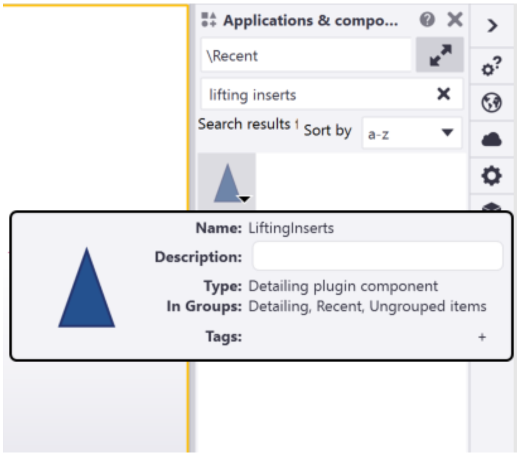


Figure 54. Lifting insert location

After selecting the lifting inserts, the assembly was selected in the model and the lifting insert was created automatically. In the properties, the “Peikko PNLF Loop” was chosen as the “Lifting Component” and “PNLF6” was chosen in the “Attribute File” tab as shown in Figure 55. The lifting part position was also defined. The mark of center of gravity on the element was also turned on.

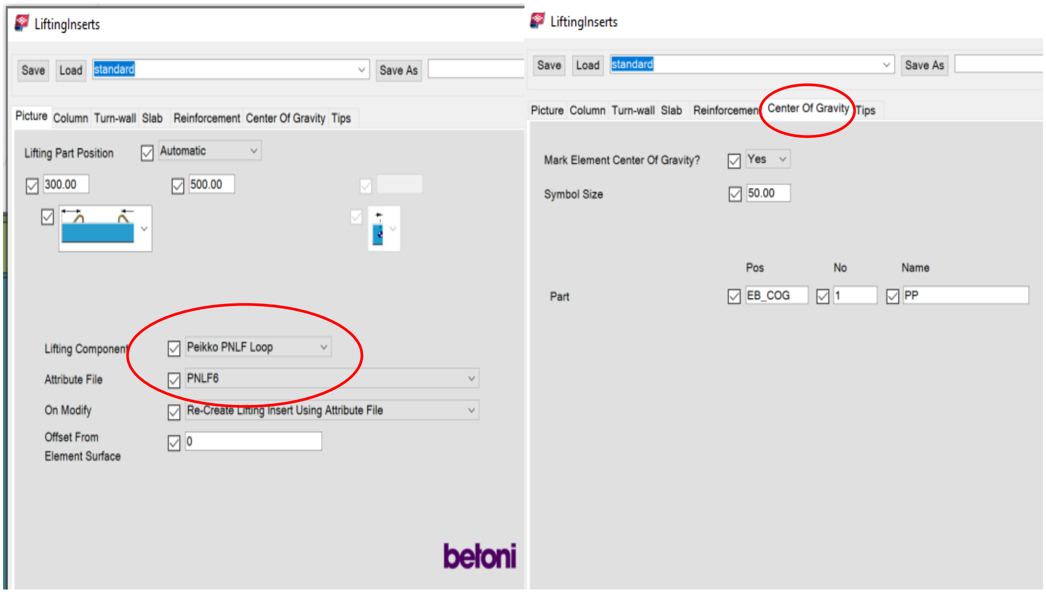


Figure 55. Lifting inserts dialog box

After inserting the lifting inserts, the lifting hooks were inside the insulation layer. So, "Part cut" tool was used, and part cut was done in the insulation by creating a beam of required size and deleted after the part cut as in Figure 56 below. The insulation will be filled in the gap once the installation is complete on the site.

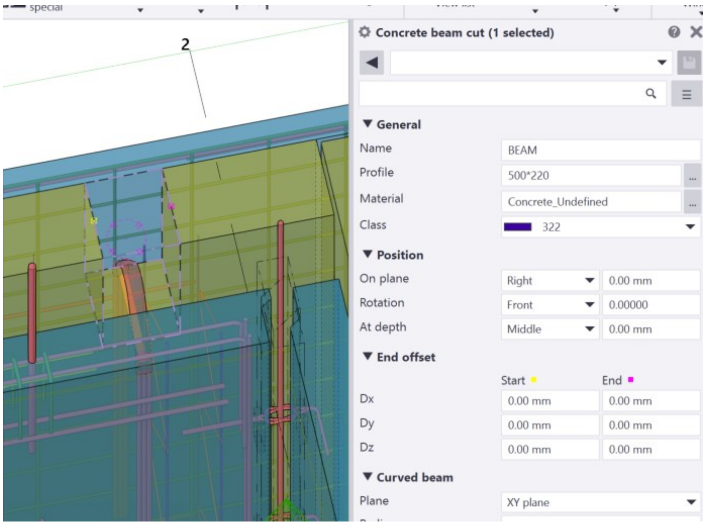


Figure. 56 Part cut insulation layer

5.10 Wall support (Vemo inserter)

Basically, all elements should be supported with at least two supports, unless the consultant specifies otherwise. The supports should be anchored to the fastening sleeves fixed in the element, and adequately fastened with expansion bolts to the concrete foundation, flooring, or floor plates. The supports shall not be removed earlier to the final stabilization of the building or possibly of a construction phase unless the project manager or the supplier allows for this.

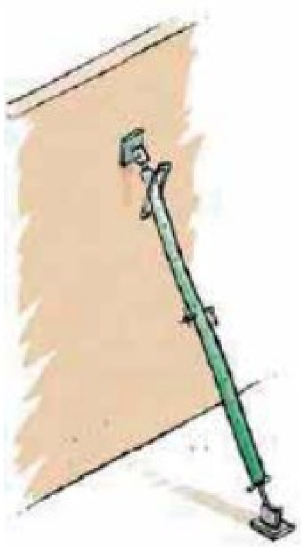


Figure 57. Wall support (Rakennusteollisuus, n.d.)

Vemo inserter is steel fasteners that can be installed on concrete before hardening to which various fastenings can be made after the concrete has hardened. Vemo transfers the load of the wall to the surrounding floor with the support beam or steel rails. The load resistance of Vemo largely depends on the depth of the gripping part from the concrete surface. There are different types of Vemo inserter available in the market depending upon their shape and size. Some of its types can be seen in Figure 58 below.

Figure 58. Types of Vemo Inserter (Semtu, n.d.)

"Wall Vemo Inserter" plugin can also be downloaded from the Tekla Warehouse. But it was not available for the student version of Tekla Structures. Thus, the Vemo in the model was created manually. A steel beam of profile D12 of length 60 mm was installed in the inner concrete layer which was 15 mm deep from the surface. The support was named "VEMO 1140" which makes it easier to understand the exact type of vemo used in the model. Then a hole of 25 mm diameter was also created using the part cut tool as in Figure 59.

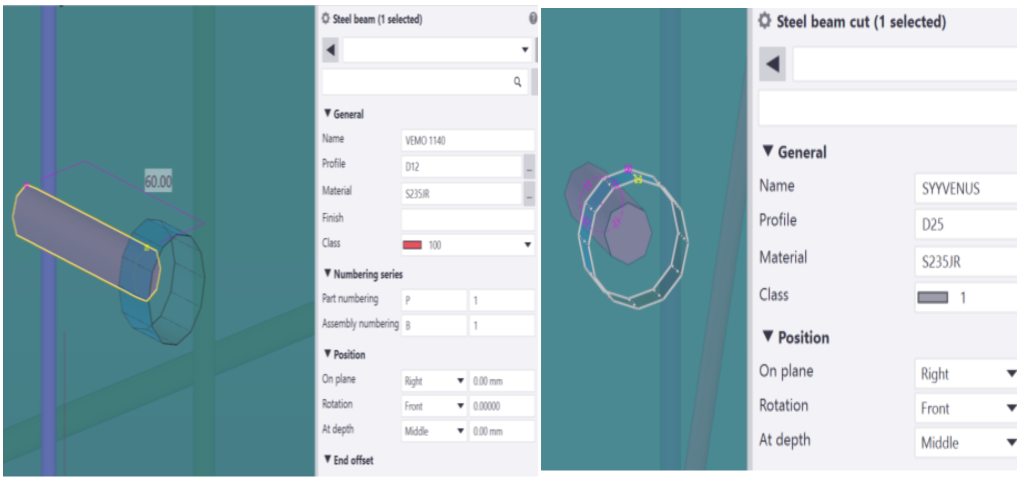


Figure 59. Creating a wall vemo inserter manually

Then the vemo was copied and aligned. The positioning of the vemo in the panel is shown in Figure 60 below. The vertical positioning of the Vemo was one-third of the height of the inner leaf from the top position.

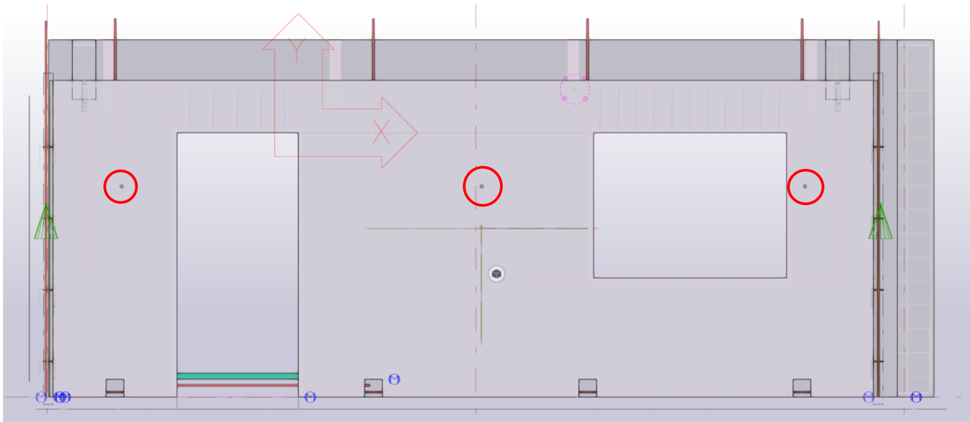


Figure 60. Positioning of the Vemo Inserter

5.11 Creating a safety steel rails and transport wood

The main purpose of putting steel rails on top of the wall is to create a platform for safety precautions during assembly to prevent people from falling from heights. Fall protection is compulsory from a height of maximum of 2.5 meters or lower. The base for the rail will be installed in the wall and the extension will be added in the site.

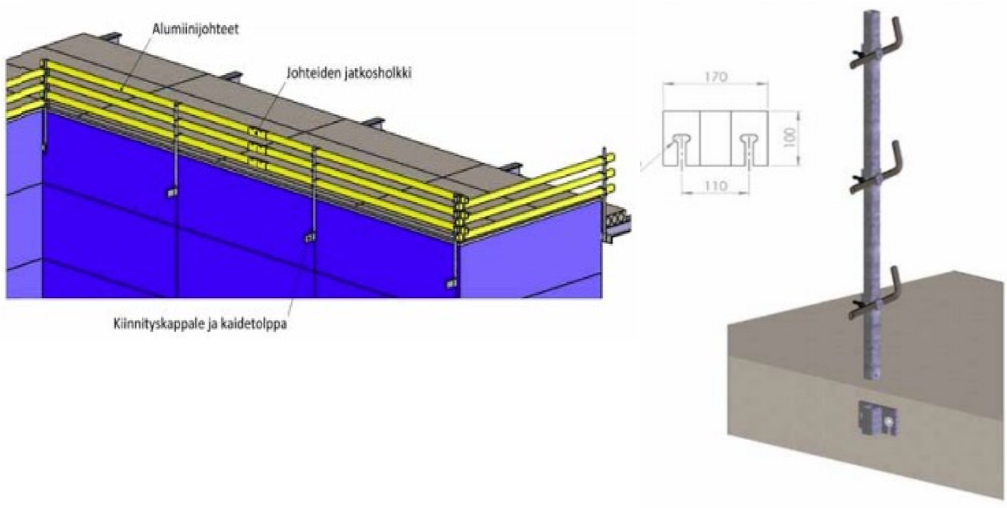


Figure 61. Rails and Barriers (Vepe, n.d.)

Steel rail was created by simply creating a stell beam of height 600 mm on the insulation layer. The profile of P100*5 and the material of S235J2 was selected as shown in Figure 62 below.

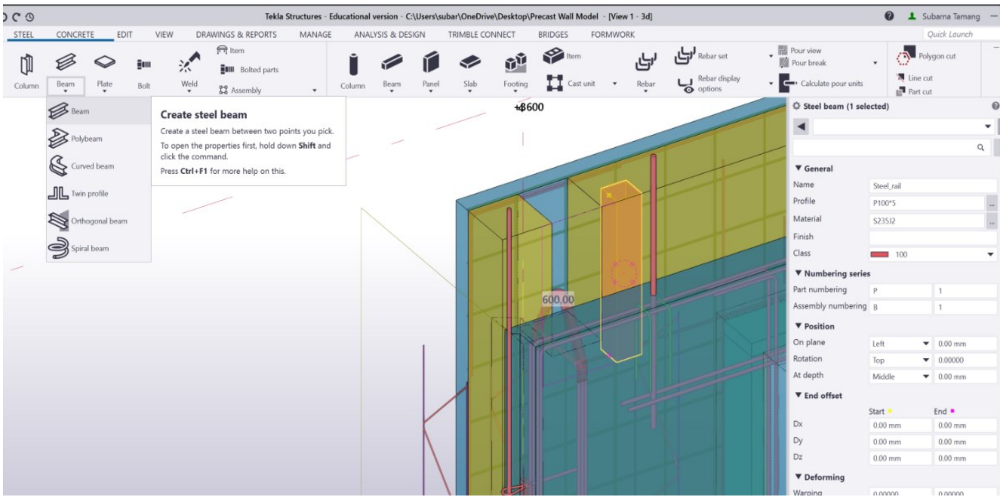


Figure 62. Creating a steel rail

Then the created rail was copied and placed on the panel as in Figure 63 below.

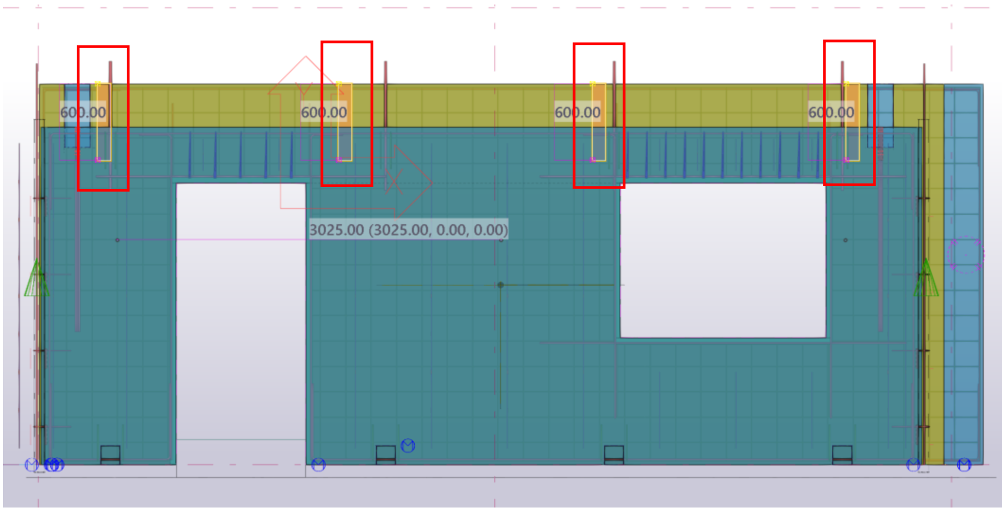


Figure 63. Positioning of Steel Rails

There is a higher chance of breaking a precast element especially in the door opening during transportation. So, it is important to put a wooden frame beam and a rebar on the door opening that connects both sides of the door and acts as a whole element. Once installed, they will be removed on the site.

To create the transport wood, a steel beam of length 1020 mm was created on the door opening. Then the profile of 100*50 and timber as the material was chosen from the properties box as shown in Figure 64 below. Also, single rebar of size T16 and grade B500B was added to make it stronger.

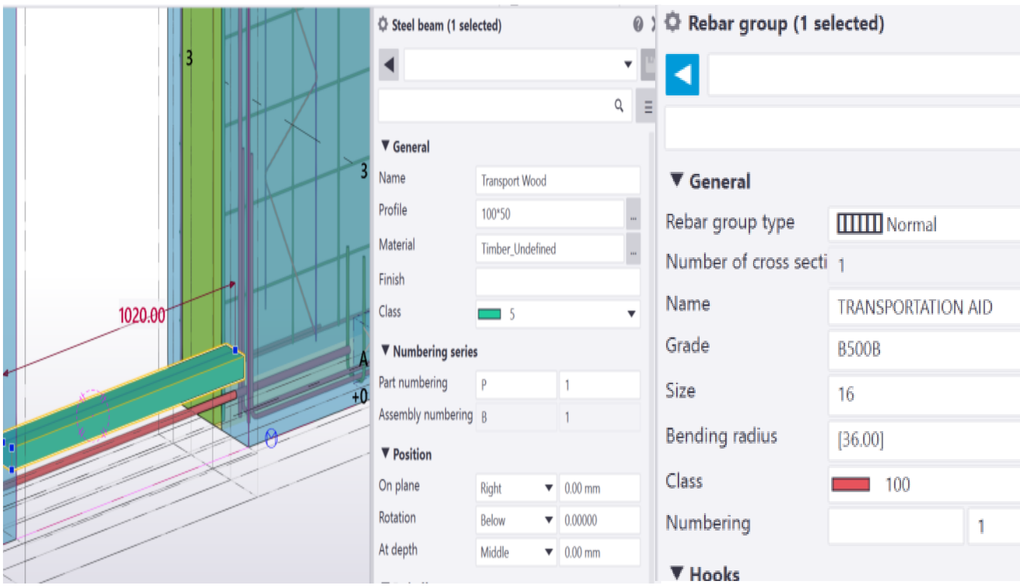


Figure 64. Creating a transport aid

5.12 Preparation of element drawings

5.12.1 Numbering and naming of elements

Before making drawings or exact reports, we need to number all parts in the model. General arrangement (GA) drawings do not require to be numbered.

Numbering is the essential key to the production output, for example, drawings, reports, and NC files. Numbers are also required when we export models. Part numbers play a vital role in the fabrication, shipping, and erection phase of a construction. Tekla Structures allocates a mark to each part and assembly/cast unit in a model. The mark contains a part or assembly prefix and position number, and other elements, such as profile or material grade. It is helpful to recognize the parts with numbers to see which parts are similar and which are different. Identical parts have the same number, which helps in the planning of the production easily.

Elements are named in element plans with an identifier consisting of a letter combination according to the type. The table below shows the letter IDs for the different wall element types. There may be multiple items of similar elements so, it is recommended to use a separate sequential ID numbering for the elements to identify the individual element.

Wall elements	Partition	V
	Partition wall (wall beam)	BOS
	Square element (load-bearing)	S
	Box element (non-bearing)	R
	Inner shell element (load-bearing)	SK
	Inner shell element (non-load-bearing)	RK
	Inner shell element (load-bearing, insulation + plaster)	SKR
	Inner shell element (non-load-bearing, insulation + plaster)	RKR
	Strap element (load-bearing)	NK
	Strap element (not load-bearing)	OF
	Shell element	KE

Figure 65. Element IDs of wall elements (Elementtisuunnittelu/julkisivut, n.d.)

After finishing the modelling, the whole element was selected by turning on the “Select assemblies” from the bottom switches box. Then by simply double-clicking the panel, the properties of the element were changed. The element was named as Sandwich element and numbered as “-101” as shown in Figure 66. The numbering is done logically so that the symbol shows directly where the element is. For example, the first partition of the 1st floor of the house is named as S-101 where 1 means the first floor and 01 means the first element of that floor.

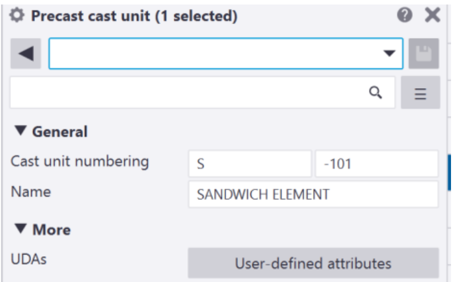


Figure 66. Cast unit numbering of element

5.12.2 Creating a cast unit drawing

The first element drawing was created using the “Cast unit drawing” function in the “Create drawings” menu. Tekla structures automatically create an element drawing that can be opened from the “Document Manager” tab. After opening the drawings, the properties of the drawing were changed as per the needs. Usually, companies have their own drawing template which can be loaded directly from the setting.

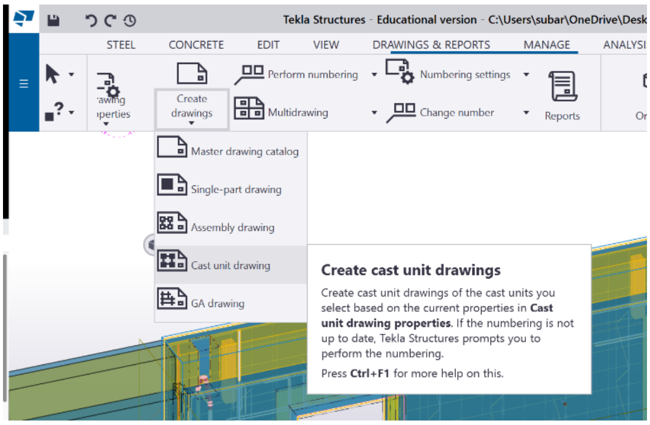


Figure 67. Creating a cast unit drawing

The first page of a created drawing (see Appendix 1, page 1) includes the 3D view of the model, reinforcing bar list, design input information, product information, embed list, bar schedule and some project names and designer name. The design input information and product information were modified by opening the "User-defined attributes" tab. For the design input information, the planned lifetime for the inner and outer leaf was given 100 years and the exposure class of XC3 and XC1 was chosen to the outer and inner leaf, respectively. In the "Product information" tab, the concrete cover and surface treatment were defined for both inner and outer leaf as shown in Figure 68.

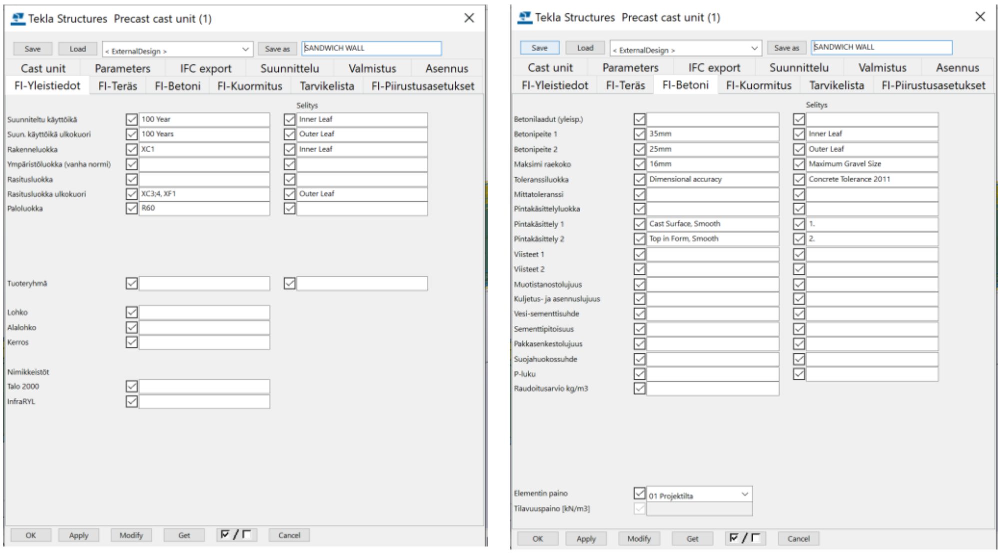


Figure 68. Design Input and Product Information

Exposure class for the concrete were selected according to the Eurocode. Concrete inside the building with low air humidity falls under exposure class XC1. Thus, for the inner concrete layer, XC1 was chosen as the concrete exposure class. Similarly, concrete which is exposed to the outer environment fall under exposure class XC3. So, XC3 was chosen for the outer concrete layer.

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs

Figure 69. Concrete exposure class (Eurocode EN206-1, 2008)

The reinforcing bar list and embeds list comes automatically in the drawing. Whereas the Bar schedule was created in AutoCAD and the DWG file was imported in the drawing. The language of the drawing was also changed from the properties. The name for the project, designer name, checker name, date of completion and number of pages in the drawing were given from the properties as shown in Figure 70 below.

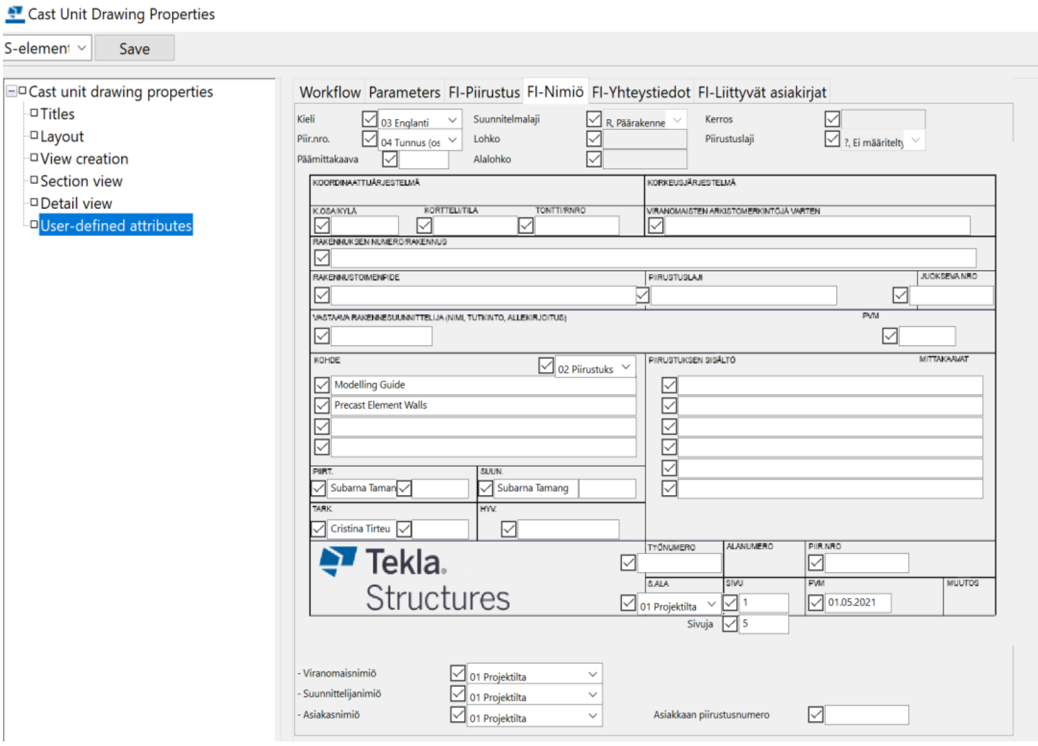


Figure 70. Cast unit drawing properties

The second page of the drawing consists of the 2D view of the model and the dimension of every detail. The required horizontal and vertical dimensions were added simply by selecting the "Dimension" (see Appendix 1, page 2). Then section views of the wall were created and kept on the different page (see

Appendix 1, page 3). From the section view, more detailed drawings were generated, and detailed dimensions were given.

The 4^{th} and 5^{th} page consists of the reinforcement details of the inner and outer leaf of the wall. The details of every reinforcement were marked in the drawings. The reinforcement mark properties were modified. The reinforcement details can be seen in the pages 4 and 5 of Appendix 1.

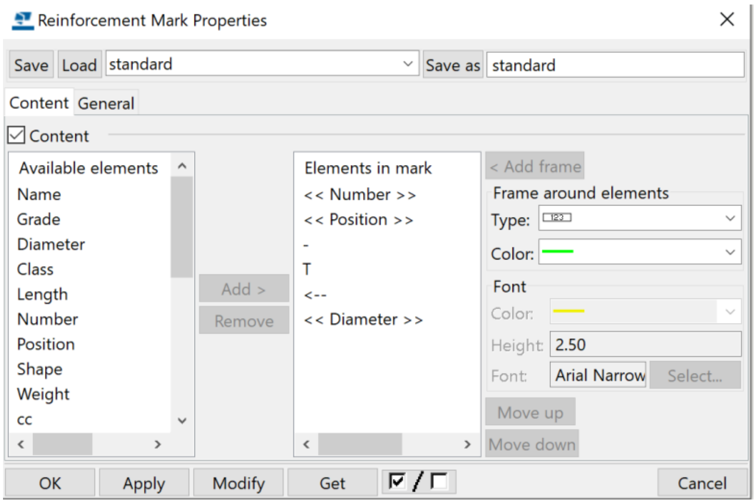


Figure 71. Reinforcement mark properties

5.12.3 Printing the drawings

Once all the details of the drawing have been drawn and checked, the pdf files were generated using the "Print" command. The finished elements are typically banked in a project bank. The location in the bank must be clear. Each house or block and element type has its own folder. Printed paper copies of the elements are ordered by the designer to the factory, or the factory prints the manufacturing images from the bank itself. Appendix 1 (pages 1-5) shows the finished cast unit drawings of the wall element.

6 CONCLUSION

The main objective of this thesis was to create a modelling guide for a precast wall element using the Tekla Structures. A sandwich wall element was modelled in Tekla Structures and the process involved while modelling and generating the production drawings of the element was explained in detail. Every single detail such as the type of concrete, reinforcement details, insulation material, the horizontal and vertical connection of the element, lifting inserts, wall vemo inserter, safety railing, etc. has been explained in this thesis. This thesis was written in an accessible manner so that it can be easily understood by users who are new to Tekla Structures. All the steps were visualized by photos of the actual process.

The theoretical part includes brief general information about precast construction and its uses. It also includes the role of BIM in the precast industry and how BIM software such as Tekla Structures is widely used in the structural modelling of the precast element. The theoretical part also briefly describes about the modelling instruction guide for designing prefabricated elements (BEC2012) produced by Betoniteollisuus ry in collaboration with Elementtisuunnittelu and Tekla Structures in 2012.

The work was limited to modelling a single sandwich wall element only. The scope and the workload of the project would have increased if the thesis had dealt with the load calculation. There was not any real project while modelling the element. However, that goal set for the thesis has reached. This thesis can be used for the educational purposes for the individuals who want to learn modelling in Tekla Structures. It can also be used by the engineering companies as a manual for their interns.

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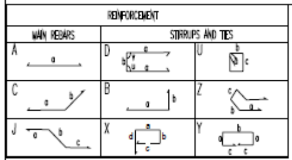
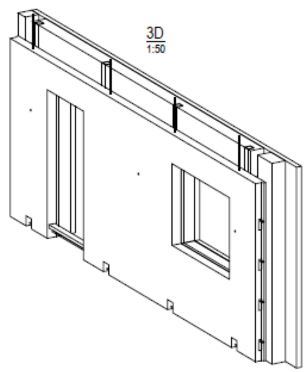
APPENDIX 1. S-101

REINFORCING BAR LIST

REINFORCING BARS ***	POS	PCS	GRADE	D [mm]	L [mm]	dL [mm]	WEIGHT SUM [kg]	a	b	c	d	e	u	v	x	TD	COMMENT
A	4	16	1.4301	5	2400		5.9	2400									
A	6	6	1.4301	5	600		0.6	600									
A	8	16	1.4301	5	250		0.6	250									
D	11	16	B500B	8	640		4.1	291	100	291						36	
U	WR/1	16	B500B	8	910		5.8										
A	WR/2	4	B500B	10	2580		6.4	2580									
D	WR/3	2	B500B	10	7960		9.8	606	6796	606						40	
D	WR/4	2	B500B	10	5900		7.3	606	4736	606						40	
B	WR/5	4	B500B	10	2800		6.9	2568	258				90			40	
A	WR/6	2	B500B	12	2290		4.1	2290									
D	WR/7	2	B500B	10	2110		2.6	606	946	606						40	
A	WR/8	2	B500B	12	2890		5.1	2890									
A	WR/10	2	B500K	7	2810		1.7	2811									
B	WR/11	6	B500K	7	1180		2.2	604	604				90			40	
A	WR/12	1	B500K	7	2270		0.7	2270									
A	WR/13	1	B500K	7	1030		0.3	1030									
A	WR/14	2	B500K	7	2930		1.8	2932									
A	WR/15	1	B500K	7	7390		2.2	7390									
A	WR/16	1	B500K	7	5290		1.6	5290									
A	WR/17	2	B500K	7	2470		1.5	2470									
A	WR/18	2	B500K	7	2870		1.7	2870									
B	WR/20	4	B500B	10	2470		6.1	258	2238				90			40	
A	WR/21	2	B500B	10	2890		3.6	2890									

REINFORCING BAR TOTAL WEIGHT [kg]: 82.5





DESIGN INPUT INFORMATION

Fire class	R60	
Exposure class outershell	XC3;4, XF1	Outer Leaf
Structure class	XC1	Inner Leaf
Planned life time	100 Year	Inner Leaf
Planned life time outers***	100 Years	Outer Leaf

PRODUCT INFORMATION

Concrete cover 1	35mm	Inner Leaf
Concrete cover 2	25mm	Outer Leaf
Max grain size	16mm	Maximum Gravel Size
Tolerance class	Dimensional accuracy	Concrete tolerance 2011
Surface treatment 1	Cast Surface, Smooth	1.
Surface treatment 2	Top in Form, Smooth	2.

EMBED LIST

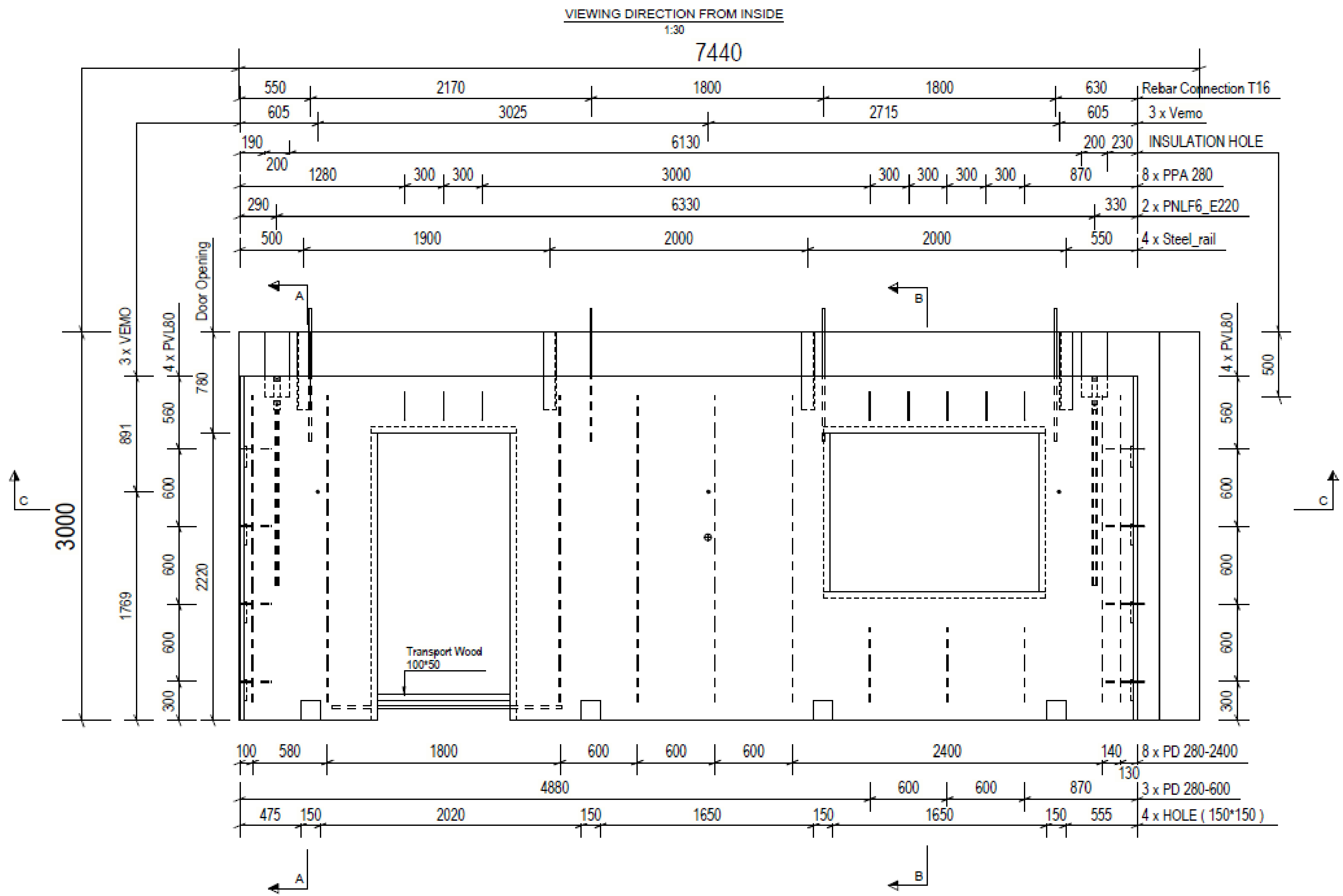
CONCRETE WEIGHT IS CALCULATED USING DENSITY 25.0 [kN/m3]
REINFORCING BARS, MESHES AND EMBEDS WEIGHT IS INCLUDED IN THE DENSITY

DRAWING NUMBER	PCS	MATERIAL	AREA [m2]	QUANTITY	UNIT
S/101	1	C30/37	18.08	3.55	m³

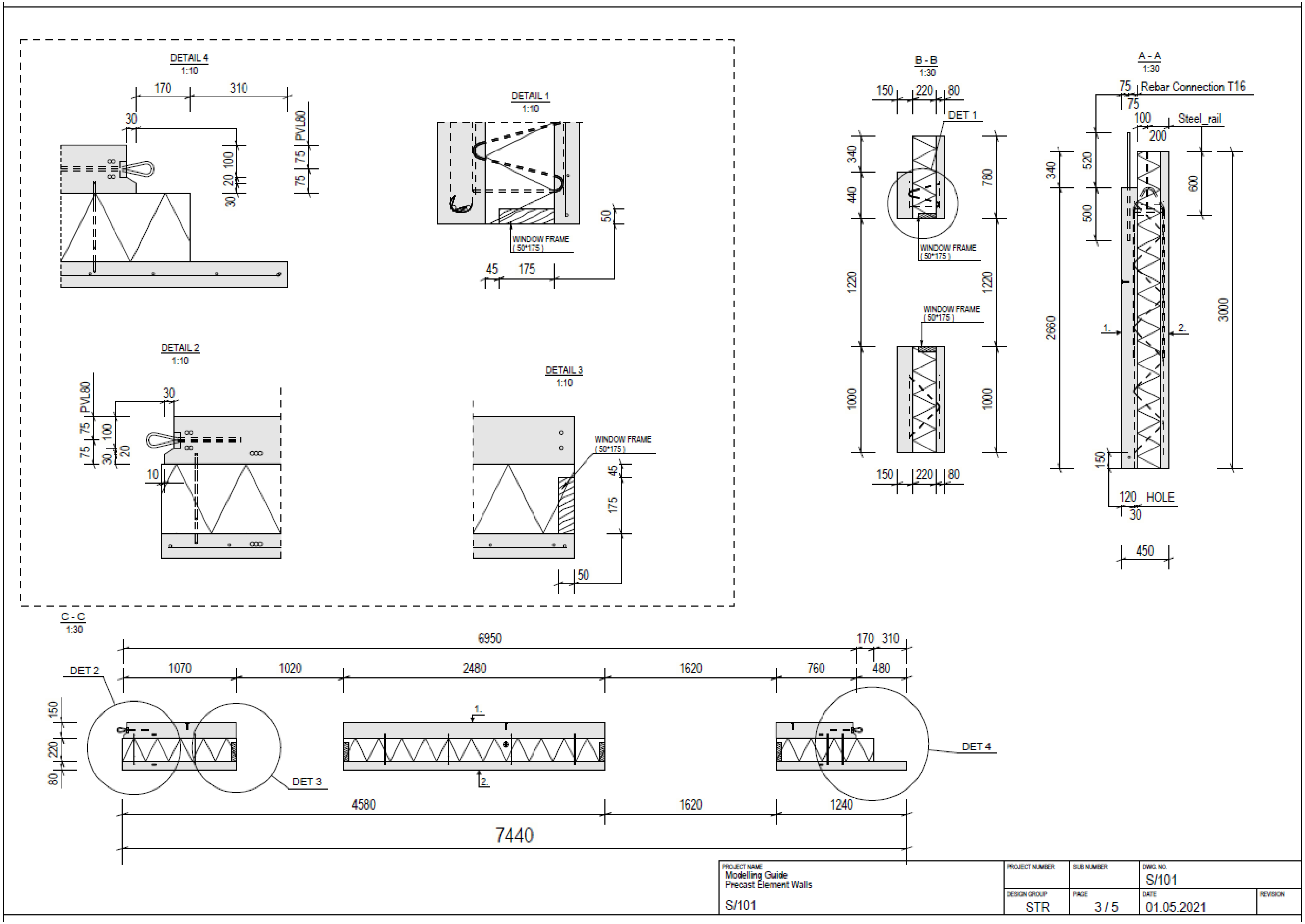
ELEMENT TOTAL: 9.01 t

Qnty		EMBEDS
16.95	m²	INSULATION EPS60S 220mm
2	kpl	PNLF6_E220
8	kpl	PVL80 PVL connecting loop
4	kpl	Steel_rail S235J2
3	kpl	VEMO 1140 S235JR
3	kpl	PD 280-600 1.4301
8	kpl	PD 280-2400 1.4301
8	kpl	PPA 280 1.4301
4	kpl	Rebar Connection T16 B500B
1	kpl	TRANSPORTATION AID B500B
52.6	kg	MESH 7/200 AISI304
7.1	kg	1.4301 ø 5
9.9	kg	B500B ø 8
42.7	kg	B500B ø 10
9.2	kg	B500B ø 12
13.7	kg	B500K ø 7

PROJECT NAME: Modelling Guide Precast Element Walls		DRAWING CONTENT: ELEMENT DRAWING S/101, SANDWICH ELEMENTTI	SCALES: 1:10 1:30 1:50
DRAWER: Subarna Tamang	DESIGNER: Subarna Tamang	CHECKER: Cristina Tirteu	ACCEPTOR:
Powered by Trimble Tekla		PROJECT NUMBER: / SUB NUMBER:	DWG. NO.: S/101
		DESIGN GROUP: STR / PAGE: 1 / 5	DATE: 01.05.2021 / REVISION:



PROJECT NAME	PROJECT NUMBER	SUB NUMBER	DWG. NO.	
Modelling Guide Precast Element Walls			S/101	
	DESIGN GROUP	PAGE	DATE	REVISION
S/101	STR	2 / 5	01.05.2021	



DETAIL 4
1:10
170
310
30
PVL80
100
75
20
75
30
DETAIL 1
1:10
WINDOW FRAME
(50*175)
50
45
175
DETAIL 2
1:10
PVL80
30
75
100
75
30
20
10
DETAIL 3
1:10
WINDOW FRAME
(50*175)
45
175
50
B - B
1:30
150
220
80
DET 1
340
440
780
WINDOW FRAME
(50*175)
1220
1220
WINDOW FRAME
(50*175)
1000
1000
150
220
80
A - A
1:30
75
Rebar Connection T16
75
100
Steel_rail
200
340
520
600
500
2660
1.
2.
3000
150
120
HOLE
30
450
C - C
1:30
6950
170
310
DET 2
1070
1020
2480
1620
760
480
150
220
80
1.
2.
DET 3
DET 4
4580
1620
1240
7440
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Modelling Guide
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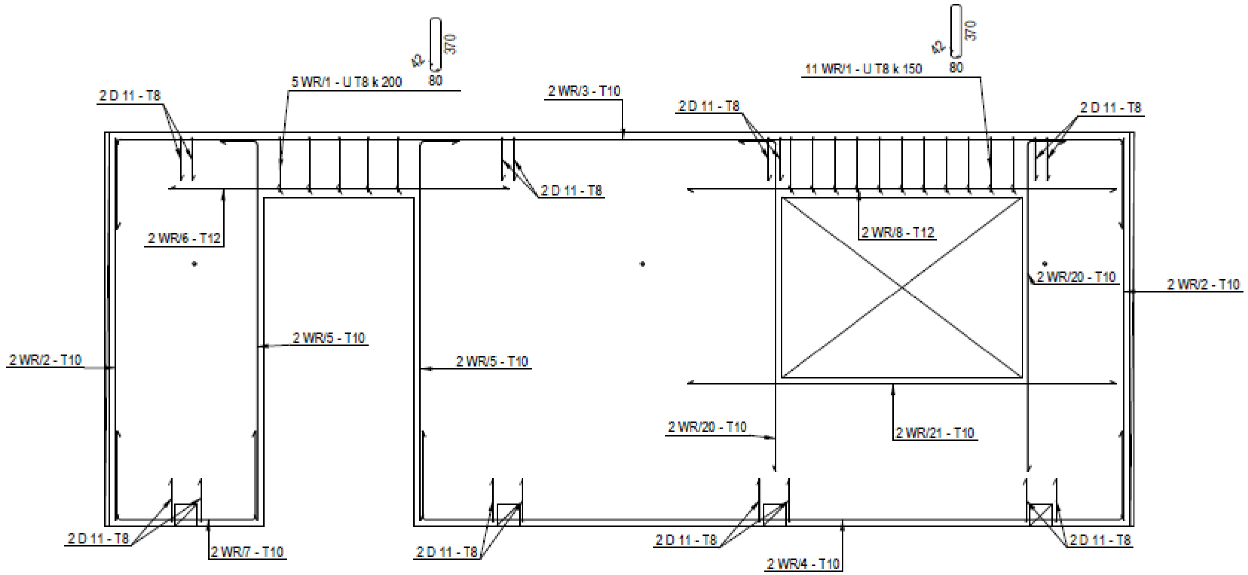
REVISION

INNER LEAF REINFORCEMENT

1:30



PROJECT NAME	PROJECT NUMBER	SUB NUMBER	DWG. NO.	
Modelling Guide Precast Element Walls			S/101	
	DESIGN GROUP	PAGE	DATE	REVISION
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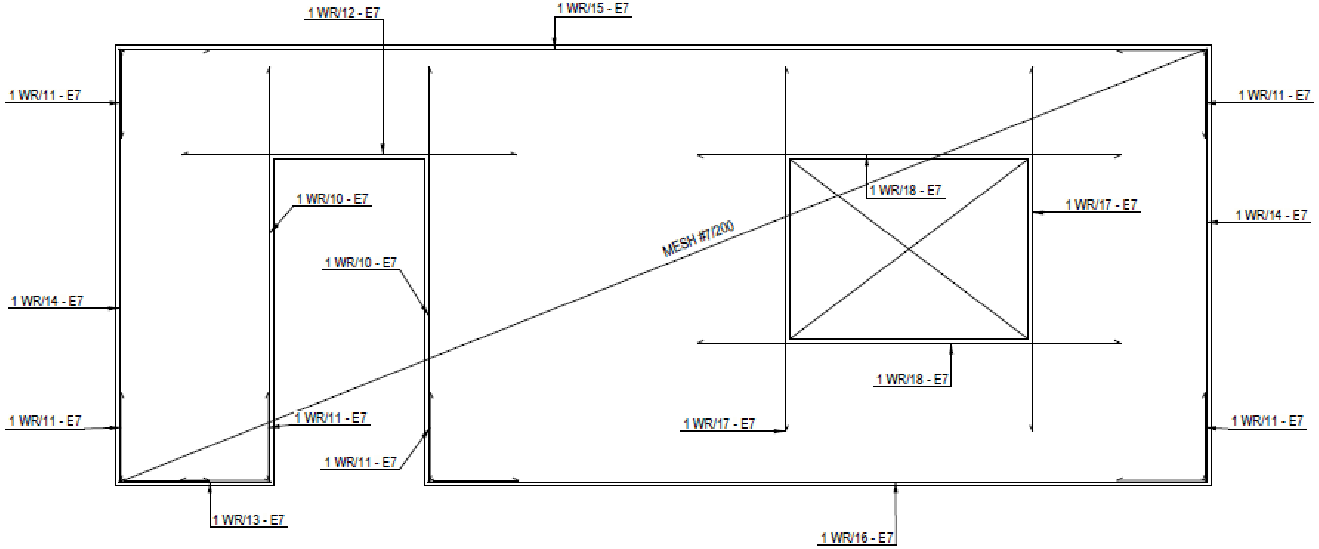
OUTER LEAF REINFORCEMENT

1:30



PROJECT NAME	PROJECT NUMBER	SUB NUMBER	DWG. NO.	
Modelling Guide Precast Element Walls			S/101	
	DESIGN GROUP	PAGE	DATE	REVISION
S/101	STR	5 / 5	01.05.2021	